Adaptive **A**utomation in **A**ssembly **For BLUE** collar workers satisfaction in **E**volvable context

GA number: 723828

Deliverable D1.4

Requirements book and human factors best practice guidance - Final Version

Partner responsible	Cranfield University
Contributors	TEK, RWTH, CESA, AIRBUS, ILL, ENG, KOM
Type	Report (R)
Dissemination level	Public (PU)
Date:	12/03/2018
Due Date:	M17
Version:	2.0
Status of the document	Final
Total number of pages:	85
Suggested readers:	All partners
Keywords:	User Requirements, Survey, Industrial Safety, Standards

Document History			
Ver.	**Date**	**Changes**	**Author**
0.1	10/01/2016	First draft: Alpha	Sarah Fletcher
0.1	27/04/2017	User Requirements first draft	Teegan Johnson
0.1	05/05/2017	Update based on TEK and ENG review	Teegan Johnson
0.1	16/05/2017	Update based on partners' reviews	Sarah Fletcher
0.1	07/06/2017	Final update	Sarah Fletcher
1.0	08/06/2017	Final version	Sarah Fletcher
1.1	28/02/2018	First Draft: Beta Main updates from D1.4 are: • Executive summary updated to cover Beta phase results. • Text in main body of the report includes the Beta User Requirements capture (Section 4.1). • Conclusion and Next Steps updated to detail Beta phase and next steps (Section 5) • Included in the ANNEX (I –M) is the Beta User Requirements data, including frequencies and percentage responses to items under each topic	Teegan Johnson
1.2	28/02/2018	First Draft: Beta Main updates from D1.4 are: • Text in main body of the report includes Beta phase high level requirements (Section 4.2) and Human Factors best practice guidance (Section 5).	Sarah Fletcher
1.3	08/03/2018	General review and update of document. Update based on ENG and TEK Reviews.	Teegan Johnson
1.4	08/03/2018	Update based on ENG and TEK Reviews.	Sarah Fletcher
2.0	12/03/2018	Final version: Beta	Teegan Johnson

List of authors

Company	Author	Contribution
Cranfield Uni	Sarah Fletcher	Initial draft, Alpha and Beta high level requirements and final report.
Cranfield Uni	Teegan Johnson	Initial draft, Alpha and Beta User Requirements.

List of reviewers

Company	Reviewer	Contribution
ENG	Angelo Marguglio	Document review
TEK	Jon Larreina, Patricia Casla	Document review

Executive summary

This report is the specified deliverable D1.4 'Requirements book'. The intention of this deliverable is to provide a full account of task T1.1, an exploratory investigation of 'multidimensional requirements' for the A4BLUE solution and its results. Identification of these requirements was planned as an initial activity in the project to capture requirements from A4BLUE partners that would help inform the design and scope of use case scenarios. It was intended to be multidimensional in respect of attaining requirements from various sources and divisions, both across the user level (informal or formal requirements of stakeholders) and at the high level (formal requirements bestowed upon organisations, beyond stakeholder level). As set out in the project grant agreement, the intention for this activity was also to gather the requirements cross organisational, technical, ethical and legal levels. This exploratory research involved two separate studies to capture requirements at both the user and high levels. These two studies were then revised during the Beta phase of T1.1 and detailed in this report (D1.4), the requirements of manufacturing systems of the future from participants external to the A4BLUE consortium were sought, and updates to legislation and standards were reviewed.

In the Alpha phase of Task 1.1 a bespoke online survey was designed and conducted across the Use-Case leaders of the project to capture user level requirements, aiming to gather the opinions of those involved in the application and operations of industrial work systems. The development of the Alpha survey and its results are presented in Deliverable 1.1. They are additionally presented in this report in Section 3 to provide reference for the adaptions made during the Beta phase and to provide an easy comparison of results. The survey was refined in the Beta phase by removing any biasing statements and simplification of the items to ensure each item covered a single construct and was clear and easy to understand. Where the Alpha survey was distributed internally within A4BLUE partner organisations, the Beta survey was distributed more widely through social media and to external contacts. The Alpha and Beta surveys collected quantitative data to explore strength of opinion, along with qualitative data designed to elicit individuals' beliefs to explain their opinions. Data analysis from both Phases revealed that, overall, opinions support the development of innovative new systems although the integration of novel technologies was considered more desirable than essential. Thus the Beta phase validated the findings from the Alpha phase and reinforcing their importance, indicating that individuals from organisations external to the A4BLUE consortium support the development of innovative systems.

In parallel, the other strand of exploratory research was carried out to capture high level requirements, i.e. the formal requirements to which organisations must comply that typically come from legal and prescriptive sources. The Alpha phase of this study was conducted via review of key resources and documents and results revealed a vast number of formal standards relevant in part to specific features of the A4BLUE systems. However, with much overlap and intersection across the resources it is necessary to develop a more precise definition of these features so they can be mapped to standards or used to identify gaps in existing resources. The Beta phase involved a review of the Standards and Legislation to identify and detail any updates to standards and Legislation. Of particular importance and note is the General Data Protection Regulations which is due to come into force on May 25th, 2018 and will impact how the A4BLUE solution acquires operator consent to collect and store data, along with how data is stored and maintained.

Table of Contents

List of Figures

List of Tables

Abbreviations

AML	Automation Markup Language
AR	Augmented Reality
BSI	British Standards Institution
CIO	Chief Information Officer
COLLADA	Collaborative Design Activity
EHS	Environment, Health, and Safety
EN	European Standard
ERP	Enterprise Resource Planning
EU	European Union
GDPR	General Data Protection Regulation
HR	Human Resources
IMS	Integrated Manufacturing System
ISO	International Organisation for Standards
IT	Information Technology
MAR	Mixed and augmented reality
MES	Manufacturing Execution System
OPC-UA	OLE for Process Control – Unified Architecture
PLM	Product Lifecyle Management
RD Director	Research and Development Director
SEREC	Science and Engineering Research Ethics Committee
SOA	Service-oriented Architecture
TS	Technical Standard
VR	Virtual Reality
WP	Work Package
XML	eXtensible Markup Language

1 INTRODUCTION

1.1 CONTEXT AND SCOPE OF DELIVERABLE D1.4

This D1.4 Requirements Book deliverable is designed to inform the A4BLUE project of requirements that need to be considered in the design of the project's solutions. It presents the activities conducted in T1.1 of Work Package (WP) 1, which involve the capture of user requirements (requirements of individuals involved in the application of industrial work systems) and high level requirements (formal socio-legal requirements). First, a series of initial Alpha phase tasks that were designed to identify the fundamental requirements for the design of the project's use case scenarios / examples, so that they are designed and constructed to accord were presented in Deliverable 1.1 and have been included within D1.4 from Section 2 for ease of comparison with the subsequent findings. Second, the subsequent Beta phase tasks are designed to review and update the design of the project's use case scenarios / examples so that the final industrial solutions produced by A4BLUE satisfy current and evolving requirements of users and wider socio-legal frameworks these are detailed in Sections 4 to 5 of this report (D1.4).

1.2 RELATIONSHIP OF D1.4 WITH OTHER TASKS AND DELIVERABLES

The user requirements activities in T1.1 will inform the design and development of all of the project's use cases. In the Alpha phase, this work provided a fundamental guide for the initial design of the use cases / scenarios definitions to ensure that they were constructed in accordance with the needs of users and formal socio-legal frameworks. The Beta phase work has proceeded in parallel with the further development of the use cases / scenarios definitions to provide a source of ongoing reference to ensure that they continue to follow the needs of users and formal frameworks. The relationship between the principal T1.1 tasks and deliverables, including scenarios definitions, is shown below in Figure 1. Further Standardisation activities will occur in T7.3, the relevant standards and legislation identified and reviewed within T1.1 will inform the activities of T7.3.

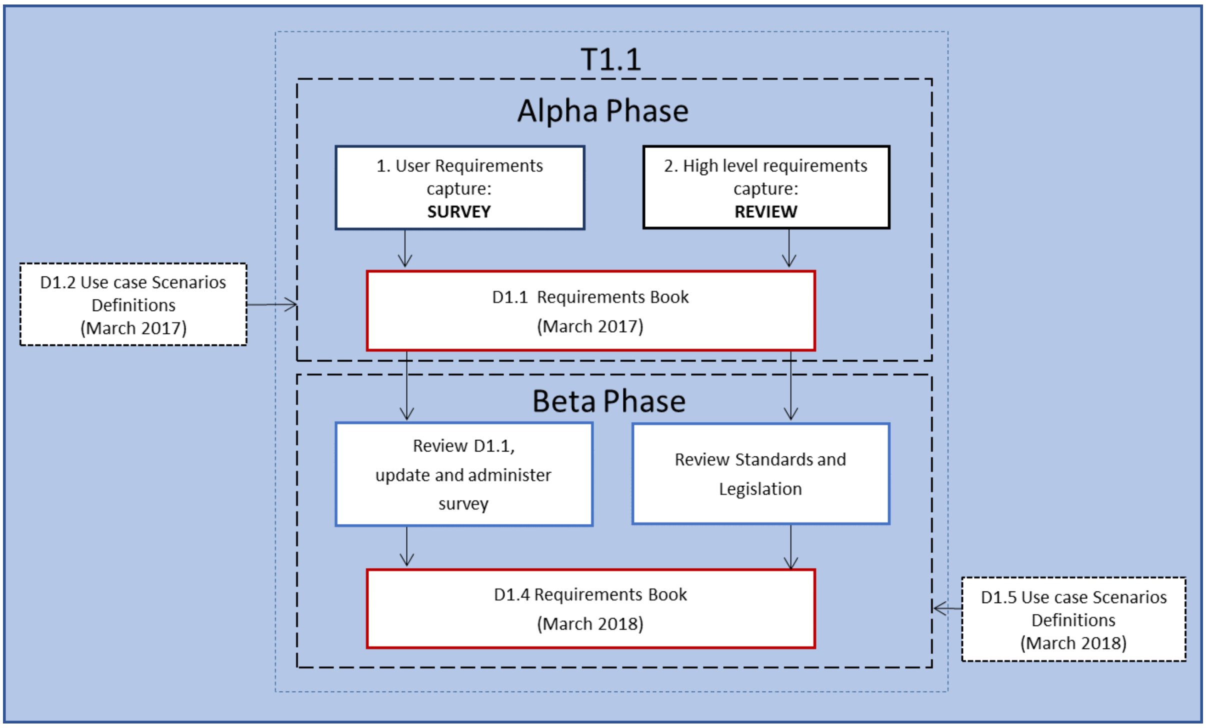

Figure 1. Relationship of D1.4 with Other WP1 Tasks and Deliverables

2 USER REQUIREMENTS OVERVIEW

2.1 USER REQUIREMENTS METHODS

A key principle of the A4BLUE concept is to apply a user-centred design approach which requires the involvement of end-users and relevant stakeholders in the definition of the relevant use case scenarios. In order to ensure a new system or process will be best utilised and operated by users it is important to begin the design process by identifying and incorporating the needs and preferences of key user groups. There is no single and universal method for requirements capture; it is adaptable according to the application in hand. Therefore, the approach adopted in this study has been developed to serve the nature and demands of the particular interests and applications of A4BLUE.

The A4BLUE project's Alpha and Beta phases are essentially designed to be developmental and testing phases. Thus, for the project's user level and high level requirements capture the Alpha and Beta phases distinguish between the early activities to capture of an initial understanding of requirements and the subsequent analysis to validate and/or identify any outstanding requirements pertinent to our use case solutions. The methods and outputs of both phases are depicted below in Figure 2.

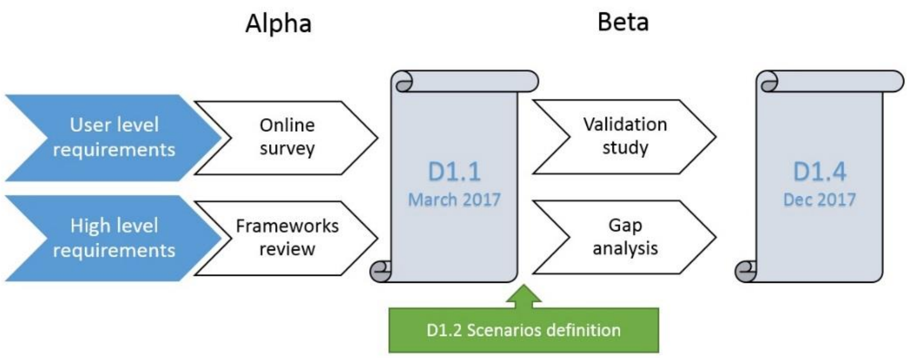

Figure 2. Alpha and Beta Phases: User and High Level Requirements Analysis

Although the delivery date for D1.4 was December 2017 (as seen in Figure 2), the deadline was extended to March 2018. This was to align with the extension provided for the Use Case Scenarios Definition (D1.5), which required more time to include feedback of developments for the Use Cases to ensure that all relevant information was included in Deliverable 1.5. This extension impacted D1.4 because the feedback was additionally used to refine the User Requirements Survey and standards and legislation review.

2.2 A4BLUE USER REQUIREMENTS

2.2.1 USER LEVEL

The selected method for capturing requirements at a user level for A4BLUE is by survey. This is because it is the most efficient way of collecting data systematically and consistently across different users in different geographical locations, organisations, and across different user groups / working roles. A survey offers a balance between a structured, organised approach and an opportunity for participants to give their own subjective opinions.

2.2.2 HIGH LEVEL

The A4BLUE definition of high level requirements refers to the various governing and guiding principles that are positioned at a formal and statutory level. Therefore, it was necessary to conduct a review of relevant legal frameworks and standards. The identification of standards applicable to this project is executed in T7.3 (reported in D7.3) and, therefore, T1.1 does not focus on selection of standards but on the evaluation of relevant content. The high level data capture proposes which specific parts of legal / standards documents need to be followed.

3 ALPHA PHASE USER REQUIREMENTS CAPTURE

3.1 USER LEVEL REQUIREMENTS SURVEY

The purpose of this first activity was to obtain an initial understanding of the likely requirements of users of the A4BLUE work system solutions via a small-scale survey of representative users from partners' organisations. It is intended to provide a formative assessment, by providing early indications of the key design priorities that should be incorporated in the design of A4BLUE use cases. The intention of the Beta phase was to collect a larger-scale and more conclusive assessment of user requirements.

3.1.1 USER GROUP DEFINITION

The first activity that needed to be accomplished before the user requirements survey could be designed and issued was to identify 'user groups'. As the A4BLUE project set out an intention to cover multidimensional users, i.e. all potential stakeholders involved in the proposed solutions, it was important to consider all types of job roles within organisations that may have a vested interest in the design and implementation of new work systems and not just direct users of the systems (operators). Therefore, four main categories were developed and grouped, as seen in Table 1 below:

Table 1 : User Groups and Subcategories

User groups	
Business	Finance / accounts
	Cost engineering
	Marketing
	Customer service
	Legal
Organisation	Senior management
	Production managers/supervisors
	Operators
	Maintenance
	Unions
Technical	System design / architect
	Technology acquisition
	Technology /system integration
	Information technology (IT)
	Life cycle engineering /management
Human	Occupational health
	Human resources (HR)
	Environment, Health, & Safety (EHS)
	Ergonomics / human factors
	Training and development

A4BLUE partners were asked to review these user groups and identify any missed groups. Three additional subcategories were suggested: Assembly planning; CIO / RD Director; User eXperience. These three suggestions were reviewed to ensure that the user groups were not individualised, which would detract from the universality of categories. Assembly planning was the only addition made as "CIO / RD Director" could fit under the "Senior management" sub categorisation, and "User eXperience" was too individualised and could fit under "Information technology" sub categorisation.

3.1.2 SAMPLE

As the purpose of this survey was to gather an early indication of user requirements, only a relatively small sample of participants were needed to represent each of the identified user groups. Therefore, it was decided that partners would be asked to recruit a small number of volunteers from their organisations to represent each user group. Table 2 presents the number of participants obtained by partners from their organisations across each of the user groups.

Table 2 : Participant Representation for Each User Group

User groups		Frequency	Total Frequency
Business	Finance / accounts	1	5
	Cost engineering	2	
	Marketing	1	
	Customer service	0	
	Legal	1	
Organisation	Senior management	1	9
	Production manager / supervisor	1	
	Operator (shop floor)	5	
	Maintenance (shop floor)	2	
	Trade union	0	
Technical	System design / architect	2	32
	Technology acquisition	3	
	Technology / system integration	8	
	IT	11	
	Life cycle engineering / management	3	
	Assembly planning	5	
Human	Occupational health	0	7
	HR	2	
	EHS	2	
	Ergonomics / human factors	2	
	Training and Development	1	

The greatest percentage of participants were from the Technical user group category, and the lowest number of respondents were from the Business user group category. It is likely that this reflects the composition of organisations who comprise the A4BLUE consortium. The largest number of participants have job roles in the “Information Technology” category. Overall there was a good spread of responses from different job roles indicating that the survey had captured the range of user requirements that are important for the A4BLUE solution across future user groups. However, three groups did not receive any contributions: customer services, trade unions, and occupational health.

One participant accidentally clicked “System design / architect” as well as “HR” and contacted the survey administrators to request that the former was removed from their selection. Consequently, this particular response had to be excluded from the data. This error indicates that a single choice option may have been a better design for this survey item, rather than a multiple choice. However, allowing a multiple selection can be suitable for capturing circumstances where participants feel they have job role overlap: the fifty survey participants provided 53 responses to this question, indicating that some participants selected more than one job role. Three participants provided two responses to this question: “Finance / accounts” and “Legal”, “Cost engineering” and “Life cycle engineering / management”, and “System design / architect” and “Technology / system integration”.

3.1.3 SURVEY DESIGN AND DATA COLLECTION

3.1.3.1 Topics

The aim of the user level requirements survey is to obtain an understanding of the likely requirements of users of the A4BLUE work system solutions, and to obtain indications of the key design priorities that should be incorporated in the design of A4BLUE systems. The topics selected for the user requirements survey were selected based on details provided in the project description (grant agreement) and in initial use case plans and user group definitions provided by partners.

3.1.3.2 Format Design

A number of specific format selections were made to ensure the survey was appropriate to meet the needs of this stage of the research, i.e. to sufficiently capture initial indications of user requirements, with validity and consistency across the partner organisations. These design decisions included the systematic means of presenting the questions for each topic, which included the use of both qualitative and quantitative questions. By ensuring that the format of the questions was the same for each topic participants did not have to decipher the meaning of the questions in each topic, after completing the first questions for the first topic they were acquainted with the format and what was expected of them. The use of this style was intended to mitigate possible cultural and language differences between participants. The development of the question, their items and the use of an online survey format were additional design decisions made to ensure the validity and consistency of responses across partner organisations. The details of these decisions are described below (sections 3.1.3.2.1, 3.1.3.2.2).

3.1.3.2.1 Online Survey

Online surveys were identified as the most appropriate format for administering the survey. The ability to send a link for the survey directly to prospective participants ensures anonymous and voluntary responses from participants which enables ethical data management. Furthermore this format provides a consistent method of administration, enabling comparisons across countries and user groups (as it is designed for all stakeholders). Additionally this format allows participants to select the survey in their language and take part in their own time so the activity was not disruptive to their work.

There are several available online survey platforms. Out of these the European Commission's EUSurvey was identified as the most appropriate platform because it is purposely designed for European surveys, is fully compliant with EU data protection laws, and is functionality suitable for A4BLUE requirements.

3.1.3.2.2 Items / Questions

It was decided that both qualitative and quantitative questions would be included to capture *strength* and *motive* for opinion. The first question of the survey involved a single closed question to gather opinions on future assembly work systems which was linked to a set of following 'items' (statements that require a simple quantitative score). This format was chosen as it precludes the need for translation of responses but also allows statistical analysis for ranking answers to establish strength of opinion. The scale for the responses was simply "Essential", "Desirable", or "Unnecessary".

Following this first quantitative section, two qualitative questions were asked. The first asked participants to provide any further comment on their answers; this was designed to gather richer explanations as to the motives for opinions. The second question then asked participants to provide suggestions; the intention of this was to generate new topics or ideas. Participants were also then asked to rate their suggestions as "Essential" or "Desirable"; this rating step made it possible to identify the criticality of new suggestions.

In the early stages of the survey design it was decided that a traffic light colour coding system for responses to the first question would increase the universal understanding of responses, and help to ensure the cross cultural validity of the survey. Therefore, "Essential" responses would be green, “Desirable” responses yellow, and “Unnecessary” responses would be red, as can be seen in Figure 3. It was intended that participants would choose a colour based on their opinion for each item. Unfortunately, this ideal format was not an available option within EUSurvey so, to compensate for this limitation, while still maintaining the system, the words were colour coded in the instructions for the survey (Figure 4) and in the item matrix for question one of each section (Figure 5).

A4BLUE

User Requirements Survey

Section B: Organisational level requirements

Essential Desirable Unnecessary

a) Please select, for each item on the list, the option that best describes your opinion to the statement ***“Assembly work systems in the future should have…”***

Functions that are able to change their behaviour autonomously to accommodate new products and production processes.	●	●	●
The ability to easily reconfigure the workplace when introducing a new automated system or robotics (e.g. plug & produce capabilities).	●	●	●
The ability to optimise by themselves to reduce the need for human intervention and adjustment.	●	●	●
The ability to reconfigure themselves to increase efficiency and minimise effort and increase efficiency when changing production processes.	●	●	●
Continuous data collection for analysis of system performance and optimisation needs.	●	●	●
Self adjusting capabilities to cope with changing needs of workforces and different worker capabilities	●	●	●
The ability to self-adjust to compensate for lower training and experience levels.	●	●	●
The ability to self-adjust to compensate for reduced technical capabilities (older computer programs).	●	●	●
On-the-job work instructions that guide the worker through assembly or support processes (i.e. inspection, routine maintenance) to reduce the need for organised off-the-job training and supervision.	●	●	●
Capabilities included in the automated system or robot that take adavantage of the available workers expertise/ knowledge.	●	●	●
Continuous interaction all systems in the organisation for resource allocation.	●	●	●
Direct connection to organisational systems for post-production product service and support.	●	●	●
Constant recording of tool usage data to a central system to improve maintenance activities.	●	●	●
Constant recording of automation / robot usage data to a central system to manage maintenance activities.	●	●	●
Monitoring work station performance for future process improvement.	●	●	●
Constant logging of production waste data for the purposes of future planning.	●	●	●
Direct connection to internal control systems (e.g. Enterprise Resource Planning, Manufacturing execution systems, etc.) to adapt the assembly process.	●	●	●
The ability to evaluate optimal levels of automation for workers (i.e. from fully automated to fully manual through collaborative).	●	●	●
Abilities for determining optimal levels of automation to meet economic requirements.	●	●	●
Capabilities for evaluating workers' levels of satisfaction of and identify potential workplace improvements.	●	●	●

Figure 3: Early User Requirements Survey Design

Instructions: how to complete the survey

Instructions: how to complete the survey

Section A asks you to select some basic demographic information. Section B then asks for your opinions on the organisational requirements of assembly work systems and Section C asks for your opinions on technical requirements. Sections B and C will both require you to review a number of potential design features that could be included in future assembly systems and a) **score** then b) **write comments.**

a) Scoring:
A list of design features which COULD be included in future assembly work systems will be shown and you will be asked to select,for each design feature, the statement which most reflects your opinion from the folowing set of three options:

'I think this is essential'

'I think this would be desirable, if it is possible'

'I think this feature is unnecessary'

b) Comments:
After you have finished scoring you will then be asked to write additional comments on the listed features and / or your scoring preferences

c) Suggestions:
Finally, you will be asked to write suggestions for any other design features that you would like to see in future work systems

Previous Next Save as Draft

Figure 4: Instructions for the Online User Requirements Survey

Organisational Level Requirements

Please select, **for each item on the list**, the option that best describes your opinion to the statement **"Assembly work systems in the future should have…"**

	Essential	Desirable	Unnecessary
Functions that are able to change their behaviour autonomously to accommodate new products and production processes.	☐	☐	☐
The ability to easily reconfigure the workplace when introducing a new automated system or robotics (e.g. plug & produce capabilities).	☐	☐	☐
The ability to optimise by themselves to reduce the need for human intervention and adjustment.	☐	☐	☐
The ability to reconfigure themselves to increase efficiency and minimise effort and increase efficiency when changing production processes.	☐	☐	☐
Continuous data collection for analysis of system performance and optimisation needs.	☐	☐	☐
Self adjusting capabilities to cope with changing needs of workforces and different worker capabilities	☐	☐	☐
The ability to self-adjust to compensate for lower training and experience levels.	☐	☐	☐
The ability to self-adjust to compensate for reduced technical capabilities (older computer programs).	☐	☐	☐
On-the-job work instructions that guide the worker through assembly or support processes (i.e. inspection, routine maintenance) to reduce the need for organised off-the-job training and supervision.	☐	☐	☐
Capabilities included in the automated system or robot that take adavantage of the available workers expertise/ knowledge.	☐	☐	☐
Continuous interaction all systems in the organisation for resource allocation.	☐	☐	☐
Direct connection to organisational systems for post-production product service and support.	☐	☐	☐
Constant recording of tool usage data to a central system to improve maintenance activities.	☐	☐	☐
Constant recording of automation / robot usage data to a central system to manage maintenance activities.	☐	☐	☐
Monitoring work station performance for future process improvement.	☐	☐	☐
Constant logging of production waste data for the purposes of future planning.	☐	☐	☐
Direct connection to internal control systems (e.g. Enterprise Resource Planning, Manufacturing execution systems, etc.) to adapt the assembly process.	☐	☐	☐
The ability to evaluate optimal levels of automation for workers (i.e. from fully automated to fully manual through collaborative).	☐	☐	☐
Abilities for determining optimal levels of automation to meet economic requirements.	☐	☐	☐
Capabilities for evaluating workers' levels of satisfaction of and identify potential workplace improvements.	☐	☐	☐

Figure 5: Online User Requirements Survey Design

When the draft survey design was complete it was reviewed by partners in the A4BLUE consortium to identify the usefulness of both the topics and their suggested items, and to gather additional items that the partners felt may have been missed. At this stage in the survey development the items were highly technical and required simplification, to ensure universal understanding of the items and to make the translation process easier. The items were first simplified by replacing technical terms with non-specialist wording. These items were then reviewed with an individual who does not work in a technical field and has a layman's understanding of technology. From this review items that remained too technical were identified and further simplified, increasing the accessibility of the items.

The survey was then uploaded to EUSurvey and a volunteer participant was asked to pilot the survey and identify any problems with the survey format, or spelling and grammar errors. The pilot assessment identified a problem with the format of the matrixes which would not allow participants to provide a response to each of the items in the matrix. This formatting was changed and the survey was reviewed to ensure that the matrix answers were working as expected. Upon completion of the successful piloting the survey was ready for translation.

3.1.3.3 Translations

The translation of questionnaires should not simply entail a single conversion of text by one bilingual individual. Translations should ideally involve a more complex process where the source language is converted forwards into the second language, backwards again into the source language and then is analysed more closely for identification of any errors or loss of meaning by another scrutinising process such as translating forwards again into the second language or by making a side-by-side comparison of the two source language versions (Harkness *et al.*, 2004). These multi-stage techniques are important to ensure the original intention and 'sense' of the text has been maintained. However, because this early user requirements survey is intended to be only an exploratory, formative activity with delivery time limitations it was decided that a simple forward translation with multi-partner testing and review would be sufficient. The protocol that was followed entailed: sending the completed survey to partners (ENG, RWTH, Airbus, and CESA) to translate, once the translations were returned they were uploaded on to EUSurvey. Partners (TEK, ENG, RWTH, Airbus, and CESA) were then asked to review the uploaded translated surveys to check that the translations were accurate and to look for any translation errors. Where possible the partners were asked to edit the translated survey online, or to contact the Cranfield Researchers and explain where changes were required. All partners who reviewed the translations online, updated the survey online.

3.1.3.4 Ethics

The development and administration of the User Requirements Survey was performed in accordance with the regulations and approval of the Cranfield University Science and Engineering Research Ethics Committee (SEREC). The instructions and format of the survey was designed to ensure ethical issues were covered, such as informed consent, anonymity, data withdrawal, etc.

3.1.3.5 Survey Administration

Once all translated surveys had been completed and uploaded to EUSurvey, the link to the survey was disseminated to all partners within the consortium, via the technical and administrative distribution lists. These partners were then asked to forward the link on the individuals they had identified during the "User Group Definition" stage (Section 3.1.2), and to any other appropriate individuals.

3.1.4 ANALYSIS

The data analysis is descriptive as it was not possible to conduct a more investigative statistical analysis due to the small sample size and spread of participants across the user groups. Summaries are presented below in turn according to each section of the survey, and greater detail of the response frequencies and percentages for each item across all of the categories / sections are provided in Annexes A to F. The overall degree to which participants agreed with items was calculated by adding together the scores that were rated as "Essential" and "Desirable" and calculating the percentage. These overall agreement scores can be found for each item in the annexes to this report.

Subsequent analysis was performed to identify the key user requirements, based on the items that were most rated as "Essential" and "Desirable", as this represented participants' priorities for future work system design. First, "Essential" items with the greatest number of responses were identified. If an item had received the same level of response the number of desirable scores were then added to determine ranking. Second, the "Desirable" items with the greatest scores were identified and ranked in a similar fashion, and where two items had the same level of response the item with the greater "Essential" frequency was ranked above the item with the lower "Essential" frequency. This method revealed the items that had been considered of highest priority by the survey participants.

3.1.5 RESULTS

3.1.5.1 Biographical Data

3.1.5.1.1 Age and Country of Participants

A total of fifty participants completed the survey and all provided their age. As can be seen in Figure 6 the greatest percentage (42%) were between 26 and 35 years of age. The age range with the smallest percentage was the 18 to 25 age range. No participants were over the age of 65 years.

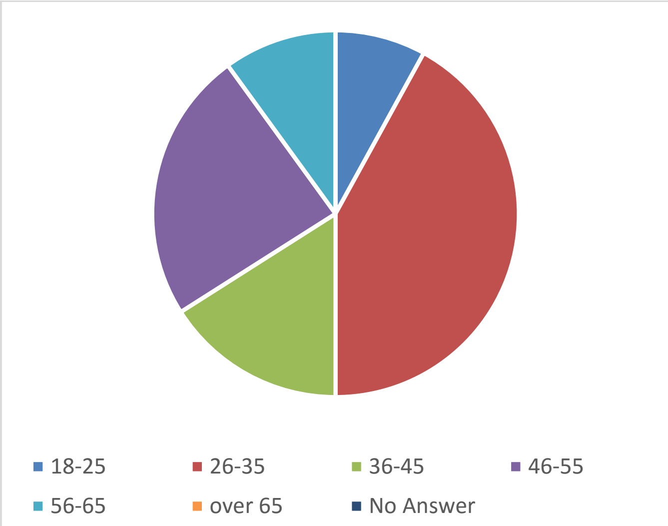

Figure 6: Alpha Participant Percentage Split of Age (%)

Figure 7 presents the countries in which participants work, and the percentage spilt of the participants across the five countries. All participants provided responses to this question. The greatest percentage and over half of responses came from Spain (56%), which is to be expected as three of the partners within the A4BLUE consortium are from Spain. The next greatest response came from Germany (26%), and 6% of participants worked in France, 6% in Italy, and 6% worked in the United Kingdom.

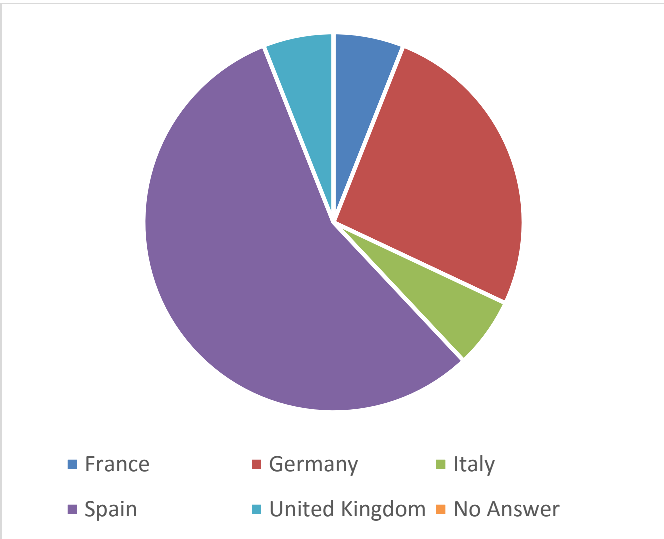

Figure 7: Country in Which Alpha Participants Work (%)

3.1.5.1.2 Manufacturing Sector

Participants were asked to identify their current manufacturing sector, the results of which are presented in Figure 8. This question returned a high number of no answers. Feedback was provided regarding this and the reason given for some of the "No Answer" results is because some individuals would have classified themselves as working within "Research" which was not an option within this survey. A "Research" subsection may be considered further if the Survey is to be disseminated to a wider audience at a later date.

Of the seventeen sectors provided, participants only report working in eight. The greatest number of responses were from the "Aerospace" and "Automotive" sectors. The four Use-Case leaders are from aeronautics, automotive and research, therefore the high response rate is to be expected for these sectors. Only a single participant identified themselves as being from the "Consumer Goods" sector, and this participant was one of three that picked multiple sectors. The participant who picked the "Consumer Goods" sector additionally picked "Automotive", and "Energy". The second participant to pick multiple responses identified themselves as working within "Electronics" and "Robotics". The third participant picked "Automotive", "Energy", "Consumer Goods", "Automotive" and "Energy", "Robotics" and "Steel & Iron". These multi responses may be from the partners within the consortia not leading the Use-Cases, such as Illogic Societa' A Responsabilita'limitata, Ingenieria Y Servicios De Automatizacion Y Robotica Komat Sl, and Engineering - Ingegneria Informatica Spa. Additionally both Fundacion Tekniker and Rheinisch-Westfealische Technische Hochschule Aachen are research institutes with individuals who may work in various sectors and may have chosen all of the sectors in which they work.

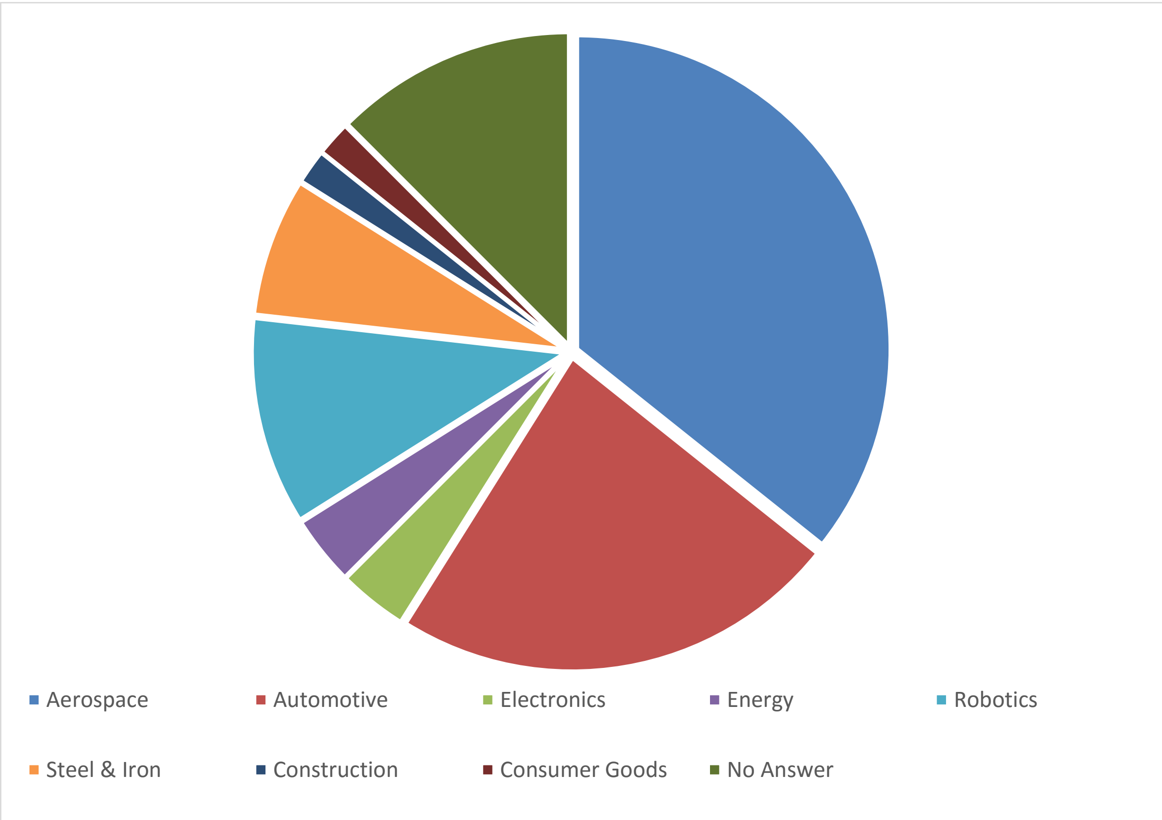

Figure 8: Manufacturing Sector (Alpha Participants)

3.1.5.2 Response Profile

Forty-nine participants responded to all sections and only one participant did not respond to the "Automation and Robotics" section. As this participant reported working in HR, it may be that they did not feel qualified to answer this section but as they did not consent to any post-survey contact it is not possible to identify whether this was the case. Overall, there was no attrition; the participant who overlooked "Automation and Robotics" questions did answer subsequent sections.

3.1.5.3 Organisational Level Requirements

Participants were asked to select whether items presented to them in the survey were: "Essential", "Desirable", or "Unnecessary" with regard to "Assembly work systems of the future". With this particular set of items covering Organisational level requirements. Therefore their focus was placed on general future work systems rather than the specific use cases, this was to ensure a more broad range of requirements was captured. By doing this it is possible to capture the expectations of future assembly work systems from those individuals within the field.

All items within the organisational level requirements responses had between 75 and 100% overall agreement, "agreement" the sum of responses for both "Essential" and "Desirable" responses. A majority of the participants have positive responses towards the items within this section and show the expectations for assembly work systems in the future. This suggests that the concepts encapsulated within these items show the requirements of the A4BLUE use-case requirements. The greatest "Essential" responses were seen for:

- "The ability to easily reconfigure the workplace when introducing a new automated system or robotics (e.g. plug & produce capabilities)" (66%)
- "Continuous data collection for analysis of system performance and optimisation needs" (66%)
- "On-the-job work instructions that guide the worker through assembly or support processes (i.e. inspection, routine maintenance) to reduce the need for organised off-the-job training and supervision" (66%)

Both the first and third bullet pointed items show the importance of flexibility within the assembly work systems of the future, to account not only for a range of products but also for the people who may work with these systems. Therefore, they should be a high priority in the use cases developed within the A4BLUE project.

Although none of the items presented had an "Unnecessary" response greater than either the "Essential" or "Desirable" scores, some scores were greater than 10%. The highest "Unnecessary" responses were for the items bulleted below:

- The ability to self-adjust to compensate for lower training and experience levels (22%)
- The ability to self-adjust to compensate for reduced technical capabilities (older computer programs) (20%)
- Direct connection to organisational systems for post-production product service and support (14%)

The highest "Unnecessary" response was seen for an item covering human capabilities. This may be a concern particularly as human capabilities is a key objective of the A4BLUE solution. It should however be noted that although these were the highest "Unnecessary" scores for this section, the highest score for each item was a "Desirable" response. These findings are reflected in the results for the System Feedback and Assistance results section, where "Unnecessary" responses were provided for items covering ergonomic support were high in comparison to other items, however the percentage of "Desirable" responses were the greatest for these items.

Participants were asked to provide additional comments about organisational requirements of future assembly systems features. Two participants provided comments:

"Focus on recentering the work of everyone on tasks with high added value"

Participant 40

"must avoid to collect data to track workers performance in order to push their limits"

Participant 48

The second of these comments concerns about the need for workers' personal data that may be collected using future assembly work systems to be treated ethically and confidentially, and that it is not used to bring harm to operators working on or using the future systems. This opinion fits with the dual objectives of the A4BLUE project for ensuring safe and ethical system security and worker satisfaction would be an appropriate requirement within the "System Security, Data Management" subsection of this survey.

Participants were also asked to provide any other ideas they may have for the design and features of future assembly work systems, and indicate their strength of opinion by marking whether they felt suggestions would be "Essential" or "Desirable". These suggestions can be found in Table 3 below:

Table 3 : Participant Suggestions for Assembly Work System Features: Organisational Requirements

Participant	Suggestion	Translation	"Essential"/ "Desirable"
10	*"Capacidad para alertar a las personas sobre medidas de seguridad y salud"*	The ability to alert people about security and heath requirements/ measurements	Essential
10	*"Capacidad para impedir daños a las personas en su funcionamiento"*	The ability to avoid damages to people while working	Essential
48	*"ensure safety of involved workers"*		Essential
48	*"ensure IT security of the work system (in order to ensure workers safety & protect from sabotage/espionage)"*		Essential
50	*"Ways for the machines to operate directly with the workforce in the same workspace safely"*		Desirable

Both participants 48 and 10 felt their suggestions were essential requirements of future assembly work systems. The first three suggestions within Table 3 are captured within other sections of the survey, however their mention here may reflect a need to include a requirement regarding operator safety within "Organisational Requirements". The final suggestion in the table was provided by Participant 48 and is addressed within the "System Security, Data Management" subsection of this survey. Participant 50 provided a "Desirable" suggestion regarding working in proximity with the robot; this is covered in the subsection directly below "Automation and Robotics". The mentioning of these suggestions early within the survey before progressing to the end to see whether they are captured later may reflect their importance to the participants.

3.1.5.4 Automation and Robotics

Participants were asked to select whether items within the list of items presented to them regarding automation and robotics were: "Essential", "Desirable", or "Unnecessary" with regard to "Assembly work systems of the future". With this particular set of items covering Automation and Robotics.

Seventeen of the twenty items presented to participants had a greater than 80% level of overall agreement. The items that had the greatest percentage of "Essential" responses were:

- Robots have safety capabilities that move the robot away from the worker in the event of an accidental collision. (74%)
- Safety capabilities that adapt the speed of the robot according to the distance or speed of the operator. (74%)
- Robots have safety capabilities that immediately stop the robot in the event of an accidental collision. (86%)
- Safety mechanisms that make operators comfortable when collaborating with automation/robots during assembly. (84%)

Three of these four items with the high "Essential" responses reflect the criticality of safety with regard to robotics and automation and therefore safety should be prominent within the list of user requirements for the A4BLUE use cases.

The items with the greatest percentages for the "Desirable" responses were:

- Automated/robotic functions that will adapt to suit operator's preferred working methods (74%)
- Automation / robotics that can change themselves safely to meet varying production demands. (56%)
- Automation / robotics that can change safely on their own to meet different experience capabilities of the involved operators. (56%)

The "Essential" response profile reflects the need for safety. However, the "Desirable" responses show the importance of meeting operator and production variations, and shows the need for flexibility in the new manufacturing workplaces to be accounted for in the user requirements book.

A greater number of "Unnecessary" responses were provided in this section than for Organisational level requirements. Items with the greatest percentage of "Unnecessary" responses are:

- Robots that do not work with or in close proximity to humans. (70%)
- Automation / robotics that run at a constant rate or on a constant programme and do not change. (60%)
- Automation / robotics that can only be adapted by management. (60%)
- Robots should work safely alongside or near to an operator but on separate tasks. (40%)

The higher frequency of "Unnecessary" responses was expected for these items, as they were negatively weighted responses and used to identify whether participants are automatically responding to questions or reading the items and then responding. They were additionally included within this section to assess participant's reaction to these types of systems and working set up. The higher frequency of "Unnecessary" responses to these items provides further evidence for the need to include flexible and human robot collaboration in the list of user requirements for the new system.

Participants were asked to provide additional comments, and two participants did so:

"Mis ideas del apartado anterior estaban incluidas en este apartado.

(Translation: My ideas from previous chapter are already included in this chapter)"

Participant 10

"some questions not well phrased and ambiguous, some feel like duplicates"

Participant 48

Participant 10 clarified that their suggestion from the Organisational Level Requirements Section had been captured within this section. With regard to the comment from Participant 48, repetition with slight variation to the question is a common practice within surveys to ensure that nuances within concepts are effectively captured.

Participants were asked to provide any additional item suggestions and these are presented in the table below (Table 4). Participant 48 again highlighted their interest in IT security questions, as presented in the previous section, which perhaps reflects the importance of this topic to them. Participant 10 suggested including an item that covered robots "teaching" operators; this is covered in the later section System Feedback and Assistance. Finally participant 50 provided advice on how to decide on the level of automation required for a task. Although informative, it does not cover the features of automation or robotics of future assembly work systems.

Table 4 : Participant Suggestions for Assembly Work System Features: Automation and Robotics

Participant	Suggestion	Translation	"Essential"/ "Desirable"
10	*"Robots que "enseñen" a las personas a realizar la tarea"*	Robots that "teach" people how to perform the task	Desirable
48	*"IT security (see previous page)"*		
50	*"During set up the task needs to be broken down and placed into the appropriate category. Manual / Semi-Auto / Auto and the levels of interaction between these systems of operation are essential"*		Essential

3.1.5.5 Communication and Interaction Mechanisms

The fourth section covered communication and interaction mechanisms of assembly work systems of the future. As with the previous two sections participants were asked to review each item and select whether they felt the item was "Essential", "Desirable", or "Unnecessary". All items presented had an agreement profile of 70% or greater, this was identified by adding the "Essential" and "Desirable" results together. The item bellow had a 100% level of agreement with 60% of participants responding that it would be a "Desirable" feature of future assembly systems:

- The automation / robot / system has visual capabilities (e.g. computer systems, lights, projected messages, etc.) to display relevant feedback and notifications to operators.

Seven items covered interaction mechanisms; two had higher levels of overall agreement:

- The automation / robot / system has both visual and auditory capabilities to present relevant feedback and notifications. (96%)
- Automation / robot / systems that can be controlled with a computer system on a mobile devise (e.g. tablet, smartphone). (94%)

This indicates that of the four items regarding feedback, visual feedback was most preferred. Both visual and auditory capabilities present a high agreement percentage (96%), with 66% of participants indicating this as “Desirable”. The item that presents only auditory feedback had the highest percentage of “Unnecessary” responses for the feedback items. Reinforcing the findings that both visual and auditory or just visual feedback should be a user requirement for the A4BLUE case studies.

The highest “Essential” responses were just over 50% for the items regarding interaction mechanisms:

- A workstation PC with an interactive computer system that allows the operator to interact and control the automation / robot / system. (56%)
- The automation / robot / system has feedback abilities to show that it has understood a command. (56%)

These items reflect current practices in interacting with manufacturing systems. The “Desirable” responses on the other hand received the greatest percentage of responses and this possibly reflects what participants would like to see in future systems. These include:

- Automation / robot / systems that operators interact with using natural speaking (i.e. non-predefined commands). (68%)
- Automation / robot / systems that can be controlled with a computer system on a mobile devise (e.g. tablet, smartphone). (64%)
- Automation / robot / systems that operators interact with using pre-defined voice commands. (60%)

A single participant chose to provide an additional comment about interaction mechanisms in the design of future assembly work systems:

“q3: emergency stop yes, handheld controller no (should have been 2 questions)”

Participant 48

This participant’s comment clarifies their response to item 3. This provides insight for consideration in future versions of the survey. Participant 48 additionally included another suggestion:

Table 5 : Participant Suggestions for Assembly Work System Features: Communication and Interaction Mechanisms

Participant	Suggestion	Translation	“Essential”/ Desirable”
48	*“Fixed mounted tablet-like device (but not a PC)”*		Essential

3.1.5.6 System Feedback and Assistance

Participants were asked to provide responses to items that covered system feedback and assistance, the overall level of agreement for all items was greater than 78%. The items with the highest percentage of “Essential” responses were:

- All tools and equipment for assembly always available to operators. (50%)
- Tools / equipment that are provided to operators at specific stages of assembly when they are needed. (56%)

Interestingly the item regarding all tools and equipment always being available to operators had one of the highest “Unnecessary” responses. Whereas a single participant provided an “Unnecessary” response to the second bulleted item above. These results indicate that just in time delivery of tools and equipment would be the preferred option in the A4BLUE use cases. Although the highest “Essential” response to items was 56%, the greatest percentage of responses was seen for the “Desirable” responses. This reflects that although the items presented are not all essential, many of the participants would like to see them in future assembly systems.

The “Desirable” response participants were the highest for items in this section:

- Augmented reality devices (e.g. google glasses) to provide remote assistance from qualified personnel to operators. (76%)
- An ability to detect when technical assistance is needed by an operator. (72%)
- The ability to recognise an operator’s capability and provides personalised assistance. (66%)

These “Desirable” response with the greatest percentage of responses are those that are personalised to the needs of the operators using the system. This reflects the need to include this type of feedback and assistance in the A4BLUE use cases where possible.

Participants were asked to provide additional comments and suggestions for system feedback and assistance features in the design of future assembly work systems, none were made.

3.1.5.7 System information and instructions

Items investigating participants’ opinions of the means by which systems information and instructions should be presented and could be adapted was the next topic of inquiry. For each items 80% or more participants agreed that the items were either “Essential” or “Desirable”, with the greatest response for all items the “Desirable” option.

Two items had a 100% agreement with no participants responding “Unnecessary” or not providing a response:

- The capability to display work procedures that show how to do tasks using multimedia capabilities (text, pictures, images, videos).
- Capabilities to allow operators to interrogate information / instructions further.

The first item had a near 50:50 split between “Essential” and “Desirable” (“Essential”: 50% and “Desirable”: 52%), with one participant unable to decide between “Essential” and “Desirable”. The second item had a greater number of “Desirable” responses (54%) than the “Essential” option “46%”. The lack of disagreement between these two items indicates the importance not only of ensuring that information is presented as clearly as possible using multiple media forms, but also for operators gain a clearer and/ or deeper understanding of the information presented to them.

As stated above the greatest percentage of scores was for the “Desirable” options for all items within this section of the survey. The two items with the highest percentage of “Desirable” scores are:

- Mechanisms for operators to directly input their own recommendations for work instructions, information updates or working conditions. (64%)
- Mechanisms for operators to directly input multimedia content (i.e. including photos, videos, and voice) into the process information and instructions. (62%).

The higher scores for these two options indicates participants felt that it is of benefit for operators to be able to interact with the work instructions they use and to provide greater insight and recommendations. A reason for this may be that by providing this capability knowledge capture, less knowledge may be lost if and when operators leave their job. Additionally this type of ability may make it easier for new operators to become proficient at a task faster.

Participants were presented with items regarding how instructions were presented to operators. On demand augmented reality (AR) had the greatest number of “Desirable” responses (58%), compared to the items covering virtual reality (VR) presenting training (56%), and AR providing information while operators complete their work (56%). Although there is only a 2% difference between these three items this may reflect the need for these new types of technology to be optional for operators. A benefit to this technology being optional for use is that it enables operators to gradually build up confidence with the technology which will aid in its adoption.

No participants chose to provide additional comments and suggestions about system performance and data features in the design of future assembly work systems.

3.1.5.8 System security and data management

The final topic posed to participants was systems security and data management. The items covered topics such as who should have access to operators and systems data, where data should be stored, what data should be captured, how long data should be held for, and the security systems that should be included assembly work systems of the future.

Three items covered access to operators data, the item with the greatest positive response was:

- Allow personnel who work on information technology systems AND managers to have access to the operator’s data

Which was a 38% “Desirable” reply for participants. This indicates that participants felt that information technology systems personnel should have access to operators’ data, rather than anybody having access which had an “Unnecessary” response of 94%. Although the results for the item covering only information technology personnel having access to operators data was very close with a 30% “Essential” and a 30% “Desirable” score.

With regard to the type of data captured by operators and where that data would be stored, greater scores were seen for the “Unnecessary” option for the items below:

- Only hold data for specific operators at specific workstations (52%)
- Capture all data about operators’ working activities (50%)

The third item within this category had a greater percentage of “Desirable” responses:

- Only capture specific data about the operator (e.g. the height they set the workbench to) (44%)

These results reflect a need to capture only specific data about operators. Within the user requirements for the A4BLUE use cases the types of human data captured and stored will need to be carefully considered. From these responses only specific data should be captured.

With regard to how long operator’s data should be kept, a “Desirable” response was the highest for the item outlining data destruction after 5 years (44%), which was reinforced by the 76% “Unnecessary” response to keeping the operator’s data indefinitely. If possible it might be of benefit for the A4BLUE use cases to have a built in automatic delete capability that reviews how long data has been kept without interaction and deletes that data after a specified period of time.

A greater “Essential” response was captured for the item covering information technology personnel and managers having access to systems data (58%), this was reinforced by the 84% “Unnecessary” response to allowing anyone to have access to systems data. This shows that, as with operator data, the allocation of access to systems information needs to be carefully considered for the A4BLUE use cases.

The greatest score for all items in this section of the survey was seen for the IT security item:

- Comprise IT security mechanisms that will prevent attacks from external sources (84%)

Participants chose the "Essential" option for this item, reflecting the criticality of ensuring that any use cases have effective security mechanisms.

Participants were asked to provide additional comments to clarify their responses or to add additional information. Two participants chose to do so:

"Cada operario/a debe poder acceder a su información, así como su responsable. TIC's debe poder acceder en calidad de garantizar la gestión, accesibilidad y seguridad de la información."

(Translation: Each operator must be able to access their information, as well as their responsible. ICT must be able to access in order to guarantee the management, accessibility and security of information.)

Participant 10

"strong personal data collection/processing rules must be applied (laws!!!); most "unnecessary" are really "undesirable" or stronger; operator data collected at station must be anonymised"

Participant 48

These comments cover data protection and who should have access to operator's data, reinforcing the findings from the first question in this section.

A single participant provided a suggestion, this suggestion is contained in Table 6. Two paragraphs have been included in the Translation column of the table. The first is the literal translation of the suggestion and the second one is an explanation of the nuance of the translation. As can be seen in the second paragraph this suggestion covers a further item regarding operator data and how long it is kept for, with operators data destroyed once they have left the company.

Table 6 : Participant Suggestions for Assembly Work System Features Relating to Systems Security and Data Management

Participant	Suggestion	Translation	"Essential"/ "Desirable"
10	*"Los datos de un/a operario/a que causa baja en la compañía deberían ser eliminados de acuerdo con los plazos legales aplicables."*	The data of an operator who causes a loss in the company should be eliminated in accordance with the applicable legal deadlines. The comment in Spanish means that when the operator leaves the company definitely and will not work there anymore, his/her data should be deleted/removed.	Essential

3.1.6 SUMMARY OF ALPHA USER REQUIREMENTS CAPTURE

The User Level Requirements survey met its aim of capturing early indications of users' requirements for the design of new work systems. Fifty participants from across the European organisations of the A4BLUE project consortium rated a wide range of potential design features as "Essential", "Desirable", or “Unnecessary” across six categories: ***organisational level requirements***, ***automation and robotics***, ***communication and interaction mechanisms***, ***system feedback and assistance***, ***system information and instructions***, and ***system security and data management***. The frequencies of these subjective ratings provided a straightforward assessment of user requirements, because those items with the most responses denote the work system design features that participants had felt were of highest priority. These user requirements are now listed and coded in order of their priority ranking, in the following ‘Requirements Book’ tables, one for each of the six survey categories.

Table 7: User Requirements: Organisational Level

1. Organisational Level	
ESSENTIAL	
Code	**Description**
1.1	Continuous data collection for analysis of system performance and optimisation needs.
1.2	On-the-job work instructions that guide the worker through assembly or support processes (i.e. inspection, routine maintenance) to reduce the need for organised off-the-job training and supervision.
1.3	The ability to easily reconfigure the workplace when introducing a new automated system or robotics (e.g. plug & produce capabilities).
1.4	Direct connection to internal control systems (e.g. Enterprise Resource Planning, Manufacturing execution systems, etc.) to adapt the assembly process.
1.5	Constant recording of tool usage data to a central system to improve maintenance activities.
1.6	Monitoring work station performance for future process improvement.
1.7	Functions that are able to change their behaviour autonomously to accommodate new products and production processes.
1.8	Continuous interaction all systems in the organisation for resource allocation.
1.9	Capabilities included in the automated system or robot that take advantage of the available workers expertise/ knowledge.
DESIRABLE	
1.10	The ability to evaluate optimal levels of automation for workers (i.e. from fully automated to fully manual through collaborative).
1.11	The ability to reconfigure themselves to increase efficiency and minimise effort and increase efficiency when changing production processes.
1.12	Self-adjusting capabilities to cope with changing needs of workforces and different worker capabilities.
1.13	The ability to optimise by themselves to reduce the need for human intervention and adjustment.
1.14	Abilities for determining optimal levels of automation to meet economic requirements.
1.15	The ability to self-adjust to compensate for reduced technical capabilities (older computer programs).
1.16	Constant logging of production waste data for the purposes of future planning.
1.17	Constant recording of automation / robot usage data to a central system to manage maintenance activities.
1.18	The ability to self-adjust to compensate for lower training and experience levels.
1.19	Capabilities for evaluating workers’ levels of satisfaction of and identify potential workplace improvements.
1.20	Direct connection to organisational systems for post-production product service and support.

Table 8: User Requirements: Automation and Robotics

2. Automation and Robotics	
ESSENTIAL	
Code	**Description**
2.1	Robots have safety capabilities that immediately stop the robot in the event of an accidental collision.
2.2	Safety mechanisms that make operators comfortable when collaborating with automation/robots during assembly.
2.3	Safety capabilities that adapt the speed of the robot according to the distance or speed of the operator.
2.4	Robots have safety capabilities that move the robot away from the worker in the event of an accidental collision.
2.5	Robots that work collaboratively and safely with an operator on shared tasks in fenceless environments.
2.6	Automation / robotics that are controllable by the operators working in the system.
2.7	Automation / robotics that can change safely by themselves to meet different physical capabilities of the involved operators, such as size differences.
2.8	Automation / robotics that can self-adapt its configuration to an operator's physical characteristics (i.e. height, arm length) to avoid potential ergonomic issues.
2.9	Safety capabilities that differentiate between people and other kinds of potential obstacles, and adapt the automation/robots behaviour to suit.
2.10	The ability to make operators aware of whether or not the safety mechanisms and devices are functioning effectively.
DESIRABLE	
2.11	Automated / robotic functions that will adapt to suit each operator's preferred working methods.
2.12	Automation / robotics that can change themselves safely to meet varying production demands.
2.13	Automation / robotics that can change safely on their own to meet different experience capabilities of the involved operators.
2.14	Automation / robotics that can change safely on their own to meet different environmental conditions like varying light and noise levels.
2.15	Functionalities to adapt the safety strategy based on the operators preferences and what is happening in the area surrounding the robot.
2.16	Automation / robots that can adapt its speed to correspond with an operator's profile (i.e. expertise, skills, capabilities, preferences, trust level).
2.17	Robots that notify management about the completion and the status of the task.
2.18	Robots should work safely alongside or near to an operator but on separate tasks.

Table 9: User Requirements: Communication and Interaction Mechanisms

3. Communication and Interaction Mechanisms	
ESSENTIAL	
Code	**Description**
3.1	The automation / robot / system has feedback abilities to show it has understood a command.
3.2	A workstation PC with an interactive computer system that allows the operator to interact and control the automation / robot / system.
3.3	Operators interacting non-verbally with automation / robot / system by using handheld controls, or an emergency stop button.
DESIRABLE	
3.4	Automation / robot / systems that operators interact with using natural speaking (i.e. non-predefined commands).
3.5	The automation / robot / system has both visual and auditory capabilities to present relevant feedback and notifications.
3.6	Automation / robot / systems that can be controlled with a computer system on a mobile devise (e.g. tablet, smartphone).
3.7	The automation / robot / system has visual capabilities (e.g. computer systems, lights, projected messages, etc.) to display relevant feedback and notifications to operators.
3.8	Automation / robot / systems that operators interact with using pre-defined voice commands.
3.9	The automation / robot / system uses sound or voice message to provide feedback and notifications to workers.
3.10	Automation / robot / systems that operators interact with using gestures.
3.11	Automation / robot / systems that operators can choose based on their preferences or capabilities to interact verbally and/or non-verbally with the automation / robot / system.

Table 10: User Requirements: System Feedback and Assistance

4. System Feedback and Assistance	
ESSENTIAL	
Code	**Description**
4.1	Tools / equipment provided to operators at specific stages of assembly when they are needed.
4.2	All tools and equipment for assembly always available to operators.
4.3	Ergonomic assessment capabilities so that it can provide postural guidance to operators.
DESIRABLE	
4.4	Augmented reality devices (e.g. google glasses) to provide remote assistance from qualified personnel to operators.
4.5	An ability to detect when technical assistance is needed by an operator.
4.6	The ability to recognise an operators capability and provides personalised assistance.
4.7	System optimisation proposal taken from feedback.
4.8	The ability to provide personalised assistance to meet the individual needs of an operator.
4.9	Knowledge capture / capitalization systems for process improvement.
4.10	Functionality for providing the assistance that operators can request and/or select.
4.11	Automated systems that suggest how to manage emergency and/or unexpected situations.
4.12	Automatic and continuous analysis of work as it is completed and feedback mechanisms.
4.13	An off-the-job system that uses virtual reality simulation to train operators to do tasks by reproducing it in a virtual world.
4.14	Assistance and feedback that is designed to keep operators satisfied as they work.
4.15	System feedback that keeps the operator aware of their own work progress.
4.16	Process analysis and feedback that can be accessed when requested by operators, such as productivity and performance information.
4.17	Ergonomic assessment of physical capabilities of the operator to provide assistance.

Table 11: User Requirements: System Information and Instruction

5. System Information and Instructions	
DESIRABLE	
Code	**Description**
5.1	Mechanisms for operators to directly input their own recommendations for work instructions, information updates or working conditions.
5.2	Mechanisms for operators to directly input multimedia content (i.e. including photos, videos, and voice) into the process information and instructions.
5.3	Functions that track operators' activity and/or work performance and inform them of recommendations and remedial actions.
5.4	The ability to verify each step of the proposed procedure and display the information related to the next step.
5.5	Capabilities that allow operators to exchange best practices/ problem solving solutions with other operators in the process instructions.
5.6	Information presented on demand using a wireless augmented reality device.
5.7	Augmented reality that provides information and instructions to operators while they are working.
5.8	Virtual reality that provides off–the-job training to operators.
5.9	Capabilities to allow operators to interrogate information / instructions further.
5.10	The capability to display work procedures that show how to do tasks using multimedia capabilities (text, pictures, images, videos).

Table 12: User Requirements: System Security and Data Management

6. System Security and Data Management	
ESSENTIAL	
Code	**Description**
6.1	Comprise IT security mechanisms that will prevent attacks from external sources
6.2	Allow information technology personnel and managers to have access to system data (e.g. data on process, data on the systems performance)
DESIRABLE	
6.3	Destroy an operator's data 5 years after they have left their company of employment
6.4	Only capture specific data about the operator (e.g. the height they set the workbench to)

3.2 HIGH LEVEL REQUIREMENTS REVIEW

To extend the multidimensionality of A4BLUE requirements, a review of 'high level' requirements has been conducted, in parallel with the user requirements survey. This activity is to identify the formal obligations that are issued at a high level of authority, beyond user levels within manufacturing organisations. In this section the high level requirements review design is described; first, the structure, scope and selection of resources are explained and then results are presented which indicate the key resources needed for the design of the A4BLUE solutions for new industrial work systems.

3.2.1 STRUCTURE

The A4BLUE proposal / grant agreement states that an analysis of high level requirements is necessary to ensure that the proposed work systems comply with "[R]equirements at an organisational level…", that are at a "technical level" (covering the essential technical features of the proposed work systems) and at an "ethical and legal level" (covering the regulations and standards for human health and safety). However, it must be recognised that there are considerable overlaps between technical, legal and ethical levels that means it is impractical to try to analyse each individually. All formal requirements, including any ethical considerations that exist, are to be found within laws and standards. Thus, it was not fitting to review the requirements of each of these 'levels' in isolation but instead to review laws and standards in a more concurrent and combined manner.

Additionally, human factors and user centred design are not only relevant across the various technical features of industrial work systems but feature in a number of laws and standards documents, individually or as part. Given these intersections, it was considered pragmatic to also review these topics in parallel. Figure 9 demonstrates the overlap of these various levels, showing how the technical features of A4BLUE systems (the technical level) are addressed by a hierarchy of requirements (including ethical and legal levels).

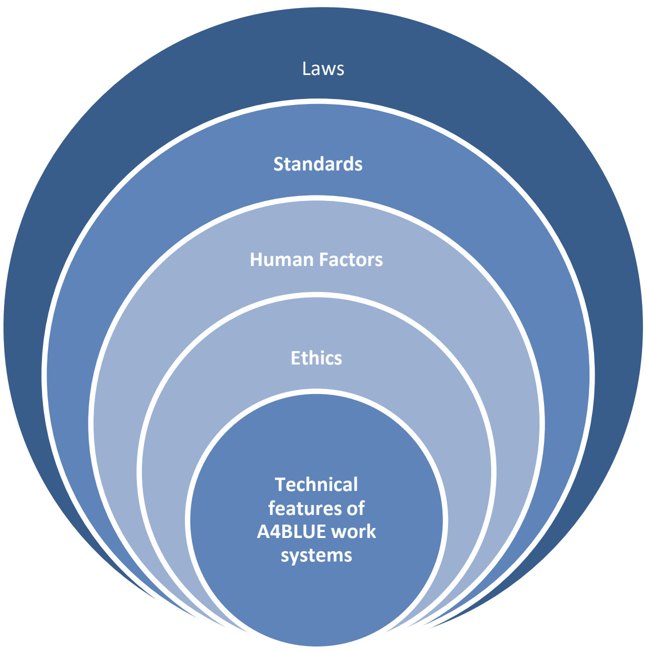

Figure 9. High Level Requirements Review Structure

3.2.2 SCOPE

Although the analysis is to be multidimensional and wide-ranging, the corpus of material that is potentially or tentatively related to new industrial work systems is vast and intersecting. So, to structure this review it was also necessary to delimit the scope of the inquiry to prioritise the needs of the A4BLUE project, focusing on the most relevant high level requirements and not on peripheral or overlapping documentation. This review therefore targets:

a) Requirements that directly govern the ***design*** of industrial systems for assembly / shop floor work, and not wider organisational aspects; A4BLUE is responsible for the development of new industrial systems but not installation and environmental or infrastructural conditions.

b) Requirements relevant to ***new*** aspects of the design or the integration of constituent technical features; A4BLUE is developing systems where a degree of product compliance to existing laws and standards must be assumed.

In terms of technical features that need to be covered in this review, standards for general industrial work / machinery safety and human factors are considered first, then those that address specific individual A4BLUE technical features (system components and technologies) are individually reviewed. Technical features described in the grant agreement include: adaptive automation and robotics, digital systems interfaces / interaction, security and data management, augmented / virtual reality, personalisation for worker capability, etc. Use case definitions need to be more precisely detailed in order to map specifications and requirements to particular features, however it is possible at this stage to determine most suitable resources.

3.2.3 RESOURCES

Requirements at the organisational level invariably concern a company's compliance with a) legal regulations, to ensure facilities, processes and procedures comply with existing law, and b) standards, to enact voluntary compliance with nationally / internationally agreed guidelines and best practice principles. Thus, in the context of A4BLUE, the key resources that need to be considered are laws and standards governing the design / supply of new industrial work systems.

3.2.3.1 Laws

Laws are typically implemented to enforce long term policy such as product safety or environmental protection rather than provide the more detailed technical specifications and recommendations that are found in standards. A4BLUE's industrial work systems need to comply with legislation governing the safe design and supply of new machinery / equipment and, as their adaptive functions will use workers' personal information, to data protection and privacy laws. Although laws do not exclusively address ethics, ethical principles are often found in relevant clauses.

3.2.3.2 Standards

Standards specify recommendations for the design and application of products, systems, processes or services, developed by expert consensus and approved by formal standards bodies. Although standards are usually adopted voluntarily and not directly enforceable, it is typical for legislation and legal enquiries to refer to standards as guidance because they provide more detailed technical specifications. Standards may therefore be considered as quasi-legal reference documents and have a strong link to legislative frameworks in Europe and associated safety related principles.

3.2.3.3 European Laws and Standards

A range of industrial machinery and safety requirements exist in different countries and regions around the world, which vary in detail and the degree of enforcement they entail. As the A4BLUE project is commissioned to develop work systems for the European Union (EU) manufacturing industry in the first instance, and EU requirements are always intentionally designed to align with international protocols, it is most appropriate to prioritise attention to EU requirements in the Alpha phase.

In the EU, requirements are developed in a process initiated by the development of 'essential requirements' (safety directives), the formation of 'technical specifications' (referring to the current state of relevant technologies), and the development of 'harmonised standards' (common principles that align the interests of different standards bodies and EU directives). Figure 10 below illustrates this process, demonstrating how EU directives become national laws, and harmonised standards become national standards, when they are adopted by individual countries.

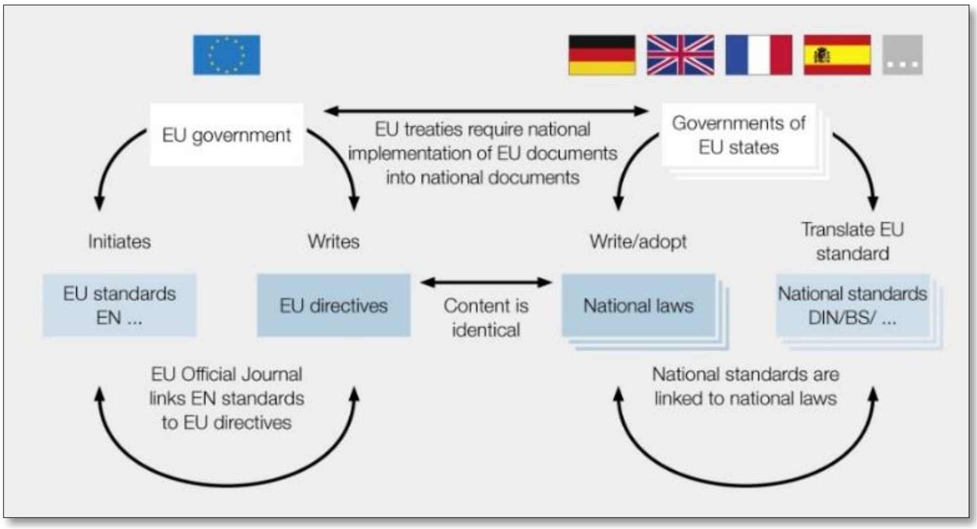

Figure 10. Relationship Between Standards, Directives and Laws in the European Union (Pilz, 2017)

As Figure 10 shows, there is a close interdependency between EU directives and standards such that national laws are in fact based on the content of harmonised standards and these are actively designed to align with international standards. This means that although compliance with standards is voluntary and not enforceable in the same way as it is to law, new products in the EU are expected to meet the requirements set out in harmonised standards (and if they do not then they must otherwise meet the essential requirements) or international standards. Thus, this review may refer to legal statutes but the principal focus is on identifying requirement from formal EU standards that provide the basis of European laws and, more usefully for A4BLUE, set out technical specifications that are most relevant to key technical features of the new industrial work systems. The review will include different defined classes of international standards (British Standards Institute, 2017):

- A-type: (basic safety standards) giving basic concepts, principles for design and general
- B-type: (generic safety standards) dealing with one safety aspect or one type of safeguard that can be used across a wide range of machinery
    - type-B1 standards on particular safety aspects (for example, safety distances, noise)
    - type-B2 standards on safeguards (for example, interlocking devices, guards)
- C-type: (machine safety standards) dealing with detailed safety requirements for a particular machine or group of machines

3.2.4 SUMMARY OF APPROACH

The design of the structure and resources selected for this review of high level requirements has been set out above to explain the methodological approach that has been taken. To summarise, there are three main principles which determine the scope of this review:

- Laws and standards will be considered in parallel but standards contain the technical specifications (including for human factors, user centred design and health and safety) that are needed for A4BLUE
- Standards that govern the *design* of industrial work systems with regard to *new* aspects or changes to component products (such that existing conformity cannot be assumed) are those in need of review for A4BLUE
- EU standards are harmonised with wider European and international laws and standards and therefore are suitably representative of the formal requirements needed for A4BLUE.

3.2.5 RESULTS

As described above, the resources that need to be reviewed in order to identify high level requirements are both laws and standards but laws set out general rules of policy that typically do not include any technical specification that can be applied to specific design cases, whereas standards do provide practical and subject-specific technical specifications that are *directly based on laws*. Therefore, for most technical aspects of the A4BLUE systems, standards will be the most relevant and accessible information regarding requirements. However, for the management of personal data A4BLUE is keen to maintain direct observation of privacy and security laws given that the new systems will capture and apply human data in new ways for the adaptive control, self-optimisation and personalisation functions. This section therefore sets out the relevant laws, for personal data management specifically, and will then present the relevant standards that apply more widely across the key technical aspects of A4BLUE solutions.

3.2.5.1 Laws

The A4BLUE grant agreement specifies a number of existing laws that need to be regarded in respect of personal data privacy and security and workers' rights. At a European level the following should be considered:

- Art. 3, 7, 8 of the Charter of Fundamental Rights of the European Union
- The Directive 95/46/EC of the European Parliament and of the Council of 24 October 1995 on the protection of individuals with regard to the processing of personal data and on the free movement of such data
- Proposal for a Regulation on the protection of individuals with regard to the processing of personal data and on the free movement of such data (General Data Protection Regulation), COM(2012) 11 final, with further changes
- Article 29 Data Protection Working Party, Opinion 4/2007 on the concept of personal data
- Art. 8 of the Convention of the Council No. 5 for the protection of human rights and fundamental freedoms
- Convention No. 108 of the Council of Europe for the protection of individuals with regard to automatic processing of personal data

The A4BLUE grant agreement also specifies that national laws need to be considered, but this is necessary only if they deviate from European directives, such as:

Spain

- Organic Law 15/1999 (13th December) on the Protection of Personal Data: this law aims to guarantee and protect personal data and sets out personal rights regarding alteration, loss, misuse or unauthorised access applicable in physical or electronic support.
- Royal Decree-Law 994/1999 (11th June), which determines technical and organisational measures to guarantee the confidentiality and integrity of personal information, including requirements for the creation of security documents.

France

- Law No. 78 17 of 6 January 1978 on ʻInformation Technology, Data Files and Civil Libertyʼ ('Law') is the principal law

Germany

- Federal Data Protection Act (Bundesdatenschutzgesetz in German) ('BDSG') which implements the European data protection directive 95/46/EC

As shown in Figure 10 EU directives become national laws when they are adopted by individual countries so A4BLUE will monitor if there are any national deviations from European directives as part of the Beta phase gap analysis.

3.2.5.2 Standards

As described previously in Section 2.2.2, A4BLUE's T7.3 activities (reported in D7.3) identified key standards, whereas the activities of T1.1 are designed to provide a more in-depth scrutiny of the *contents* of standards, to detect aspects that are most applicable to this project. The content of individual standards was found via internet searches using ISO (international), EN (European) and BSI (British) search portals but, in particular, via British Standards Online due to the direct access available to Cranfield. As a result, most of the standards reviewed are BSI standards, i.e. the UK implementation of European or international standards accepted without changes and equivalent to ISO or EN versions. All documents reviewed here are fully referenced at the end of this report so that they may be located and scrutinised in more detail by partners as required. Page numbers provided in this section correspond to the particular documents referenced and no other versions.

The structure of the results section is as follows:

- 3.2.5.2.1 European Machinery Directive standards
- 3.2.5.2.2 Automation and robotics standards
- 3.2.5.2.3 Ergonomics and human factors standards
- 3.2.5.2.4 Digital systems standards

3.2.5.2.1 European Machinery Directive standards

The supreme legal governance of industrial work and machine safety in EU countries comes from the European Machinery Directive 2006/42/EC; this has *"the dual aim of harmonising the health and safety requirements applicable to machinery on the basis of a high level of protection of health and safety, while ensuring the free circulation of machinery on the EU market"* (EC, 2010, p.1). As EU directives are so closely related to specific harmonised European standards which provide more detailed technical specifications it is most useful to identify and review the most relevant standards for A4BLUE.

The European Machinery Directive includes all industrial equipment and many of the related harmonised standards are relevant to the manufacturing context. The challenge in this review was to identify those which sufficiently address the requirements of the industrial work systems being produced within the project and omit those which are out the scope. For example, although a number of standards address key A4BLUE system components, such as IT equipment or protective measures, they are not useful if they do not cover application or integration of components as in the project. If functional characteristics, performance or safety of components will not be changed by their integration in A4BLUE systems it is reasonable to assume products' original conformity to standards remains intact. So, the standards harmonised with the European Machinery Directive that have been considered most directly relevant are included here, but as the exact configuration of components in use case systems still being determined the review can be extended or adapted during the project's subsequent Beta phase.

3.2.5.2.1.1 A-type Standard for European Machinery Directive 2006/42/EC

- *EN ISO 12100:2010 Safety of machinery — General principles for design — Risk assessment and risk reduction*

This is the single A-type standard for the European Machinery Directive which sets out general concepts and requirements which should be considered fundamentally relevant to all new machinery. Section 5 presents a procedural model for risk assessment (replacing previous separate risk assessment standards). This would be a useful protocol for A4BLUE use case developers to follow when systems are at a more mature stage of development (see p.10). Section 6 provides a number of risk reduction measures and basic human-system principles. These may be valuable as reference points for use case developers in A4BLUE but do not sufficiently specify technical requirements, so it will be necessary to consult B-type standards (cross-referenced in the document) for guidance on selection and assemblage of specific system components. [NB: no C-type standards are relevant].

It is worth noting that a particularly useful reference point for A4BLUE is found in section 6.2 on 'Inherently safe design measures' as this underlines the importance of integrating protective machine characteristics to circumvent human error and violation without the need for guarding and auxiliary protective devices. Its endorsement that inherently safe design measures are *"the first and most important step in the risk reduction process"* (p.23) provides A4BLUE with a strong rationale for integrating sensor based human monitoring safety measures.

3.2.5.2.1.2 B-type standards for European Machinery Directive 2006/42/EC

A full list of the B-type standards for the European Machinery Directive is provided in Annex G. A number of these could be discounted immediately as irrelevant but the others needed to be considered as either *highly relevant* or *potentially relevant*. For the purposes of this review only standards that are considered to be highly relevant, i.e. those that provide technical specifications / requirements, have been included at this stage. Other standards that simply provide general principles and definitions, or address wider organisational / environmental issues were considered out of scope. The selected standards are now described with key aspects and relevance to A4BLUE outlined.

- *ISO 13849-1:2015 Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design*

This first part of the standard is designed to provide general requirements for the design and assessment of the safety-related parts of control systems (SRP/CS) using programmable electronic system(s), including the design of software. These general principles include performance levels for safety functions but not the design requirements of specific cases or products that are parts of SRP/CS. It is, therefore, a relevant basic reference guide for risk assessment and risk reduction in the design of A4BLUE's automated systems.

- *IEC 60204-1: 2016 Safety of machinery – Electrical equipment of machines – Part 1: General requirements.*

This standard is designed for the design of *electrical, electronic and programmable electronic equipment and systems to machines not portable by hand while working, including a group of machines working together in a co-ordinated manner" (IEC, 2016)*. It is a recent revision to incorporate important new technical changes relevant to equipment commencing at the point the supply's connection to the machinery's electrical equipment. The A4BLUE report D7.3 identifies this standard as potentially relevant *"in the design of the electrical circuits of the A4BLUE automation mechanisms"*.

- *EN 614-2:2000 Safety of machinery – Ergonomic design principles – Part 2: Interactions between the design of machinery and work tasks +A1:2008.*

This second part of EN 614 is selected because it sets out technical requirements for industrial machinery work tasks, providing *"analysis and specification of functions and their allocation to the machine or the operator as part of the design process…"* (p.5). This corresponds with A4BLUE design requirements. Part 1 'Terminology and general principles' provides secondary reference points.

Section 4.1 of the standard prescribes ideal 'Characteristics of well-designed operator work tasks' which provide generic guidance for the design of A4BLUE systems. Section 4.2 then recommends a 'Methodology of work task design in relation to machinery design' consisting of five stages which relate to some extent with A4BLUE plans:

1. Establishing design objectives
2. Function analysis
3. Function allocation
4. Work task specification
5. Assignment of work tasks to operators

The remaining sections of the document specify how machinery work task design should be conducted, and this is ideal guidance for A4BLUE. The first recommended stage – establishing design objectives – is currently being addressed by the *requirements capture* and *use case scenarios definition* Alpha phase activities for WP1. Following that, in the Beta phase of WP1, there will then be activities to meet the requirements of the second recommended stage – function analysis – when Cranfield conduct task decomposition analysis and use case owners further develop and update their system designs. It is inevitable that the subsequent tasks of function allocation, work task specification and assignment of tasks will be part of A4BLUE systems development so there is a clear opportunity to map these out formally to align work package activities.

- *EN ISO 11161:2007 Safety of machinery - Integrated manufacturing systems - Basic requirements*

This standard is selected as it sets out the way in which the key Machinery Directive A-type standard EN ISO 12100 should be applied to the context of an 'integrated manufacturing system' (IMS) which is defined as a "*whole new and different machine rather than simply its parts combined"* (p.vi). It provides *"requirements and recommendations for the safe design, safeguarding and information"* (p.1) to help system integrators to prevent risk to individuals who need to perform IMS tasks, such as inspectors and maintainers. This is relevant to A4BLUE given the project's integration of separate components to develop new manufacturing work systems.

The standard proposes a wide range of considerations that should be included in risk assessments in relation to limits, functionality, determination of work tasks, space requirements and access in various system configuration examples. Although some of these considerations might be more applicable after installation or relevant to wider organisational or environmental aspects, it would be advisable for use case owners to consider how to design for post-implementation activities as part of system life cycle.

- *EN 842:1996 +A1:2008 Safety of machinery - Visual danger signals - General requirements, design and testing*

This standard is selected because visual alarm signals are one type of protective measure that may be needed for A4BLUE systems, in order to comply with the machinery directive's fundamental A-type standard, EN ISO 12100 (sections 6.2.11.6 and 6.4.3). The standard provides guidance for the design of warning signals to achieve three key human responses: detection, discrimination and correct reaction. It recommends a hierarchy of precedence whereby visual emergency signals are of utmost priority, then danger signals take priority over all other visual signals in the environment. A number of technical specifications are recommended so that signals are:

- Clearly seen under all possible lighting conditions;
- Clearly discriminated from general lighting and other visual signals;
- Allocated a specific meaning within the signal reception area

The technical specifications cover numerous aspects of lighting such as luminosity, transmission, visibility, colour and positioning, etc. These specifications should be consulted directly by A4BLUE use case owners if they come to consider particular requirements for visual signals.

- *EN 981:1996+A1:2008 Safety of machinery - System of auditory and visual danger and information signals*

Although EN842 provides more detail in relation to visual signals, this short standard is selected as potentially useful in addition if A4BLUE use case scenarios wish to integrate auditory and / or visual signals in their systems. [NB if auditory signals are to be integrated it may be useful to additionally consider the specifications of EN ISO 7731:2008 'Ergonomics - Danger signals for public and work areas - Auditory danger signals].

- *EN 894-1:1997+A1:2008 Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 1: General principles for human interactions with displays and control actuators*

This first part of the EN 894 standard provides general principles more than technical specifications. However, it is selected because it addresses the design of systems to accommodate human task capabilities and characteristics across "physical, psychological and social aspects" (p.5), to optimise:

- Task complexity and acceptable human demands, e.g. speed, accuracy, force, or vigilance
- Functional grouping and positioning of displays and controls
- Functional positioning and consistency of associated information (text / symbol)
- Availability of system status information and redundant information
- Intuitive functionality and usability of controls
- Error correction opportunities
- Flexibility for operators to adapt system functionality to suit individual capabilities

All of these requirements align with A4BLUE aims but the final point is especially significant as it matches the key novel objective of the project: to produce systems that will adapt to different operator characteristics and capabilities. In section 4.6 'Suitability for individualisation and learning' the standard stresses that systems should be *"flexible enough to be adapted to differences in personal* *needs, general physiological and psychological abilities, learning abilities and cultural differences"* (p.10). Thus, these general principles are directly applicable to the design of A4BLUE systems and should be employed as part of the five stage process of machinery outlined above (EN 614).

- *EN 894-2:1997+A1:2008 Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 2: Displays*

Part 2 of EN 894 is selected for its provision of more precise technical specifications for displays based on all of the key principles set out in Part 1 (above): task characteristics, positioning, functional mode and content, etc. At this stage it is not possible to determine the exact requirements for A4BLUE systems so these individual specifications should be consulted directly by use case owners when considering particular displays in the design of their systems.

- *EN 894-3:2000+A1:2008 Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 3: Control actuators*

Part 3 of EN 894 is also selected for its provision of more precise technical specifications based on the general principles in Part 1, but this time for control actuators. In this standard the requirements are focused on systematic assessment and selection of suitable controls to accord with both task requirements and physical capability (grip, force, motion, etc.). For this purpose the document provides a check list method for evaluation and selection which could be used by A4BLUE use case owners if selecting controls as system components.

- *EN 894-4:2010 Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 4: Location and arrangement of displays and control actuators*

Part 4 of EN 894 is because it describes "ergonomic requirements for the location and arrangement of displays and control actuators in order to avoid hazards associated with their use" covering machinery and other interactive devices, consoles, and instrument panels (p.5). In the document a six-stage 'Design procedure for location and arrangement' is proposed in a diagram (p.7), from early design specification right through to design evaluation. This process is based on the five stage methodology set out in Part 1, which A4BLUE use case owners could use as a guide for evaluating requirements for their systems. As the standard is relatively detailed it also provides clear guidelines for determining design specifications and selections. Section 5.4.4 is particularly relevant as it is devoted to integration of the system, including the combination of technical and human characteristics and complexity.

- *EN 1005-2:2003+A1:2008 Safety of machinery - Human physical performance - Part 2: Manual handling of machinery and component parts of machinery*

Part 2 of the EN 1005 standard series is identified selected because it provides guidance for designing manual handling aspects of industrial work systems which will be an important for A4BLUE use cases where operators are required to manipulate or load / unload components. A model and process for risk assessment calculations is provided including population limits. Use case owners should refer to these provisions in order to reduce ergonomic unsuitability and risk of musculoskeletal injury as a result of their systems. Fundamental principles and definitions related to human physical performance in relation to machinery safety in this series are provided in Part 1 for reference.

- *EN 1005-3:2002+A1:2008 Safety of machinery - Human physical performance - Part 3: Recommended force limits for machinery operation*

Similarly to the above standard, the third part of the EN 1005 series is selected because it provides guidance for designing manual handling aspects of industrial work systems which will be an important for A4BLUE use cases that involve manual handling. It includes a recommended procedure for calculation of recommended population limits to reduce musculoskeletal injury risk. This is designed to "increase the flexibility and possibility for a larger population to operate the machines" which is directly relevant to A4BLUE designing more inclusive work systems for diverse workforces.

- *EN 1005-4:2005+A1:2008 Safety of machinery - Human physical performance - Part 4: Evaluation of working postures and movements in relation to machinery*

This final part of the EN 1005 series of standards addressing human physical performance related to machinery safety proposes specifications for reducing posture related musculoskeletal risks. A great deal of the recommended process for risk assessment and task evaluation are aligned with A4BLUE plans. For example, section 4.2.3 is dedicated to advocating task analysis prior to identifying ergonomic data – this is the exact method to be employed for the human factors evaluation in use case design activities. In this respect the standard is, in general, a useful reference for A4BLUE requirements.

Conversely, section 4.2.2 may not be as compatible with the key objectives of A4BLUE use case design. This clause is entitled 'Establish the operator population' and states that "it is important to determine the range of body dimensions of the operator population". Traditionally, it has been important to identify a user population when designing a system for a particular demographic, and in such cases the designer consults anthropometrics and other physical limits pertaining to that population to ensure optimal usability. However, in A4BLUE use case design this section is probably not relevant because it contradicts the aim of optimising inclusivity by not designing for a restricted population. This clause may therefore be a potential candidate for revision as a result of the A4BLUE project.

- *EN ISO 14738:2008 Safety of machinery – Anthropometric requirements for the design of workstations at machinery*

This standard provides fundamental guidance on anthropometrics, dimensions and allowances for the design of industrial workstations. It provides a range of ergonomic / postural requirements for seated and standing positions. These are basic considerations in human-system design but potentially useful, particularly if used in conjunction with human parameters provided in other standards.

The above standards are all those harmonised to the governing EU Machinery Directive which is the highest current governance of industrial work systems, and therefore most relevant to A4BLUE. In addition, a number of other existing standards that address particular technical features that are likely to be relevant to the A4BLUE solutions are now discussed.

3.2.5.2.2 Automation and Robotics Standards

Automation and robotics in industry has been evolving in recent years. Robots have traditionally been hazardous, heavy payload systems which require total isolation from human operators but today there is a fast-growing development of smaller force- and torque-limited systems which enable closer proximity and cooperative working with people. The laws and standards for robotics are therefore changing and trying to catch up with technology advances, and to deal with the significant changes to working environments being brought about by these new 'collaborative systems'. The design of these smaller and safer robots may still be more aligned to standards for the non-industrial robotics, such as healthcare and social robots, but there is a need to consider how they may be integrated in industrial systems and, therefore, to review the relevant clauses of industrial standards.

- *EN ISO 10218-1:2011 Robots and robotic devices — Safety requirements for industrial robots – Part 2: Robot systems and integration*

In the first part of this standard (Part 1: 'Robots') the technical specifications concern *"safety in the design and construction of the robot"* (p.vi). Given that A4BLUE systems will not be designing and constructing robots but will be integrating existing COTS systems, these requirements are not highly relevant unless a specific aspect is pertinent because the act of integration alters the robot's performance / functional safety. However, this second part of the standard is selected because it provides a comprehensive level of detail concerning the application of an industrial robot and "*the way in which it is installed, programmed, operated, and maintained*" (p.v). This standard also demonstrates its intersection with other key standards, sitting directly between part 1 and the ISO 11161 standard for integrated manufacturing systems (Machinery Directive B-type, reviewed above). A revision of the standard will commence later in 2017.

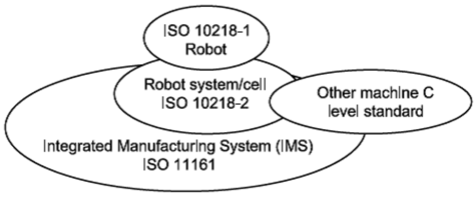

Figure 11: Graphical Representation of Standards-Robot System Relationships (EN ISO 10218-1:2011)

- *ISO/TS 15066:2016 Robots and robotic devices — Collaborative robots*

This new standard has been developed to address the rising need for technical specification for collaborative robots. It is a technical standard (TS) at this stage because, due to the infancy of the topic, more application knowledge needs to be gathered before a full ISO standard can be developed. Nonetheless, this technical standard is highly relevant to A4BLUE because it is the foundation for future EU standards and laws which will become high level requirements. It may also be a suitable target for the dissemination of A4BLUE results for the update of current knowledge and standards, as the TS will be revised in approaching years to develop it into a full ISO standard; it is currently being reviewed / adopted in a number of countries.

- *BS 8611:2016- Robots and robotic devices. Guide to the ethical design and application of robots and robotic systems*

There are very few standards devoted to ethical principles. This innovative British standard is a new endeavour to supply ethical principles for different types of robots within the categories of industrial, personal care and medical, in response to the significant current growth of robotics in these areas. As such, the principles are generic and do not deal with the specific issues that are important to industrial robot applications. However, the novelty of this standard in addressing psychological safety in addition to physical safety corresponds well with the novelty of the A4BLUE project which also aims to optimise aspects of psychological wellbeing. Additionally, it does address issues that are likely to be relevant to A4BLUE systems, such as: functions that use personal data (e.g. characteristics / satisfaction), automatic collection and analysis of performance data, and the design of collaborative robot systems.

3.2.5.2.3 Ergonomics and Human Factors Standards

Ergonomics / human factors is an overlapping and intersecting component of laws and standards and for which there are a number of separate dedicated standards that may be relevant for the A4BLUE industrial work systems. General ergonomics principles and definitions can be found in EN ISO 26800:2011.

- *EN ISO 9241 Ergonomics of Human System Interaction*

ISO 9241 is a large multi-component series of international standards covering a number of topics that are relevant to A4BLUE:

- 100 series: Software ergonomics

- 200 series: Human system interaction processes
- 300 series: Displays and display related hardware
- 400 series: Physical input devices - ergonomics principles
- 500 series: Workplace ergonomics
- 600 series: Environment ergonomics
- 700 series: Application domains - Control rooms
- 900 series: Tactile and haptic interactions

The entire series is extensive, but from this there are a number of parts that appear to be of greater importance to the development of new industrial work systems solutions and are therefore recommended as reference points for determining requirements:

- Part 100: Introduction to standards related to software ergonomics
- Part 110: Dialogue principles
- Part 129: Guidance on software individualization
- Part 161: Guidance on visual user interface elements
- Part 210: Human-centred design for interactive systems
- Part 303: Requirements for electronic visual displays
- Part 400: Principles and requirements for physical input devices
- Part 410: Design criteria for physical input devices
- Part 920: Guidance on tactile and haptic interactions

Given the breadth of this multi-part standard system it is considered pragmatic that use case owners and human factors researchers refer to this list as appropriate during the definition and development of A4BLUE systems.

- *EN ISO 6385:2016 Ergonomics principles in the design of work systems*

This standard is selected because it provides fundamental requirements that should be included in work station / system design within integrated multidisciplinary approaches that balance consideration of human, social and technical requirements. This clearly aligns with the multidisciplinary and balanced approach of the A4BLUE project. The standard advocates that work system design incorporates:

- design of work organisation
- design of work tasks
- design of jobs
- design of work environment
- design of work equipment and interfaces
- design of workspace and workstation

It is worthwhile considering how each of these design considerations should ideally be addressed, and this could provide a framework for the design process and evaluation / inclusion of requirements. Many individual aspects are contained elsewhere in standards harmonised to the Machinery Directive but this is an overall assemblage of human-centred issues.

Section 4 of the standard proposes a range of human-centred criteria for post-implementation evaluation and monitoring of system designs. These measures might be useful for A4BLUE benchmarking:

- health and well-being
- safety
- system performance
- usability
- cost-benefit

Moreover, section 4.7 suggests that conforming to the standard involves satisfying the given requirements and specifications, identifying applicable recommendations, stating whether those have been followed, and explaining why if any have not.

- *EN 10075-1-2000 Ergonomic principles related to mental workload Part 2: Design principles*

Basic principles and definitions are provided in Part 1 of EN 10075 for reference but this second part is selected because it addresses design principles to optimise cognitive load which is a key consideration in the design of work tasks, particularly those involving levels of automation. In A4BLUE, where a key objective is to integrative self-adapting automation, a suitable level of mental workload will be a major design concern. Workload is a function of all / any system components.

Although parameters are not given, a range of issues that should be considered in design are addressed that might be useful for A4BLUE evaluations.

- *EN ISO 14915-1:2002 Software ergonomics for multimedia user interfaces. Design principles and framework*

This standard is selected as a relevant source of requirements for any multimedia interfaces that will be integrated within A4BLUE systems. The greater complexity of multimedia user interfaces means human factors and ergonomics considerations are even more imperative for A4BLUE systems. Assimilation into an integrated manufacturing system design is likely to increase complexity and, therefore, mental workload. The three aspects that need to be addressed according to this standard – the design of content design, interaction, and media – are considered to be especially in need of investigation in relation to the task characteristics and work design process activities outlined in EN 614-2:2000. In particular, the development of a worker satisfaction modelling and feedback mechanism will need to accord with standard interface requirements and this may be an area of standards that could benefit from update via dissemination of A4BLUE results.

3.2.5.2.4 Digital Systems Standards

Digital systems is a broad term used to describe any system where digital technologies and interfaces are employed by humans / to assist human functions. In the development of the UR survey, contributions from A4BLUE partners confirmed that digital systems needed technical features for: Communication and Interaction Mechanisms, System Feedback and Assistance and System Interaction and Instructions. Within these categories the project plans to involve a number of more specific technologies including digital interfaces for control and feedback, AR/ VR for training and instructions, human analysis, and data security. Standards have therefore been sought in relation to these aspects to provide a foundation for requirements capture but these will be monitored as the project progresses. Due to the relatively early stage yet fast pace of current technology development, it is also likely that the formal requirements for these technologies will be advancing throughout the project, so they will need to be monitored and updated in the Beta phase. For the present review a number of resources are selected as potentially relevant according to the different technical aspects.

3.2.5.2.4.1 AR / VR

Currently, no standards exist specifically for the design and application of AR or VR in the manufacturing industry. For the development of computer game / multimedia IT applications a limited number of standards have been drafted (e.g. ISO/IEC 14772-2:2004 Information technology. Computer graphics and image processing. The Virtual Reality Modelling Language. External Authoring Interface (EAI); ISO/IEC 18039. Information technology. Computer graphics, image processing and environmental data representation and coding of audio, picture, multimedia and hypermedia information. Mixed and augmented reality (MAR) reference model). The need for formal requirements to cover general AR / VR device interfaces and application interfaces is growing and, for example, the IEEE P2048 Working Group are currently working on the development of eight standards covering general applications:

- IEEE P2048.1 - Standard for Virtual Reality and Augmented Reality: Device Taxonomy and Definitions
- IEEE P2048.2 - Standard for Virtual Reality and Augmented Reality: Immersive Video Taxonomy and Quality Metrics
- IEEE P2048.3 - Standard for Virtual Reality and Augmented Reality: Immersive Video File and Stream Formats
- IEEE P2048.4 - Standard for Virtual Reality and Augmented Reality: Person Identity
- IEEE P2048.5 - Standard for Virtual Reality and Augmented Reality: Environment Safety
- IEEE P2048.6 - Standard for Virtual Reality and Augmented Reality: Immersive User Interface
- IEEE P2048.7 - Standard for Virtual Reality and Augmented Reality: Map for Virtual Objects in the Real World
- IEEE P2048.8 - Standard for Virtual Reality and Augmented Reality: Interoperability between Virtual Objects and the Real World

This sort of progress is promising and needs to be monitored by the A4BLUE project so that systems are made to conform to any new requirements as they arise. However, for *"proper development of standards for AR, there needs to be a very clear understanding of AR requirements and use cases"* (Perey *et al*., 2016) and at the current time, nothing yet fits the particular requirements for industrial / manufacturing applications of AR and VR. Therefore, A4BLUE needs to particularly monitor standards developments particularly in relation to industrial applications but, at the same time, also seek ways to disseminate findings and contribute expertise to relevant standards communities.

3.2.5.2.4.2 Human Analysis

A key objective in A4BLUE is that its solution work systems will be able to adapt various functions, such as levels of automation and feedback, to match the requirements and capabilities of individual operators and maintain their levels of satisfaction. This degree of personalisation means it will be necessary to consider formal requirements for identification of individuals. A number of standards currently exist in relation to biometric recognition and measurement which may be of some relevance, e.g.

- ISO/IEC TR 29194:2015 Information Technology -- Biometrics -- Guide on designing accessible and inclusive biometric systems

- ISO/IEC 24779-1:2016 'Information technology — Cross-jurisdictional and societal aspects of implementation of biometric technologies — Pictograms, icons and symbols for use with biometric systems —Part 1: General principles'

The current challenge is that it is not clear at this time, whilst use case designs are still being defined, which specific requirements are needed. It is likely that this developing area of the project and technology will need to be reviewed throughout the project and, if new standards are needed, might benefit from A4BLUE results.

3.2.5.2.4.3 Interoperability

To adapt to human and process variability A4BLUE should be able to exchange information with external legacy systems (e.g. ERP, MES, PLM, etc.) and involved automation mechanisms. A4BLUE and the involved interfacing systems should be able to interact using specified data formats and communication protocols. Furthermore they should have ability to automatically interpret the information exchanged meaningfully and accurately in order to produce useful results. A number of standards currently exist in relation to interoperability issues which may be of some relevance for A4BLUE.

- *EN 62264-1:2013 Enterprise-control system integration*

IEC 62264 is an international standard for enterprise-control system integration. IEC 62264 defines the interfaces between enterprise activities and control activities. This standard provides standard models and terminology for describing the interfaces between the business systems of an enterprise and its manufacturing-control systems. The models and terminology presented in this standard could be used to support integration capabilities of A4BLUE with enterprise systems.

- *EN 62541 OPC unified architecture*

EN 62541 is the standard that describes the OPC Unified Architecture (OPC UA) that supports a machine to machine communication protocol for industrial automation. OPC UA focuses on communicating with industrial equipment and systems for data collection and control by means of an open Service-oriented architecture (SOA) involving integral information model.

- *EN 62714-1:2014 Engineering data exchange format for use in industrial automation systems engineering - Automation markup language*

IEC 62714 (Automation Markup Language, AML) provides XML schema based data exchange format focusing on the domain of automation engineering. It supports the data exchange in a heterogeneous engineering tools landscape. The goal of AML is to interconnect engineering tools in their different disciplines, e.g. mechanical plant engineering, electrical design, process engineering, process control engineering, HMI development, PLC programming, robot programming, etc. AML stores engineering information following the object oriented paradigm and allows modelling of physical and logical plant components as data objects encapsulating different aspects. Typical objects in plant automation comprise information on topology, geometry, Kinematics and logic, whereas logic comprises sequencing, behaviour and control.

3.2.5.2.4.4 Data Security

The digital industrial work systems will comprise personal data collection / monitoring and, therefore, issues of data security, safety and ethics. A4BLUE systems will pay particular regard to a number of standards identified in T7.3, as well as to European and national laws. These resources to provide guidelines for information security risk management will need to be reviewed in the Beta phase gap analysis to identify any deviations from European directives / laws within particular countries.

3.2.6 SUMMARY OF ALPHA PHASE HIGH LEVEL REQUIREMENTS

This high level requirements review has identified key components of current standards that are relevant to A4BLUE. As the A4BLUE work systems will comprise a number of integrated technologies there is a large number of potentially relevant current standards and laws to consider. Some provide general principles and some attend to more specific aspects of design. It is inevitable that, in the lifetime of the A4BLUE project, existing relevant standards will be updated and new relevant standards will be created. It is therefore vital that progress is monitored and revisions are undertaken during the project. It is also highly important that gaps in requirements are identified, i.e. where available standards do not currently address the particular needs and specifications of the A4BLUE systems. In the meantime, the list of key references for high level requirements in this report is as follows.

Table 13: Selected Relevant Standards

European Machinery Directive Standards	Automation and Robotics	Ergonomics and Human Factors	Digital Systems
EN ISO 12100:2010	EN ISO 10218-1:2011	EN ISO 9241-100:2010	ISO/IEC TR 29194:2015
ISO 13849-1:2015	ISO/TS 15066:2016	EN ISO 9241-110:2006	ISO/IEC 24779-1:2016
IEC 60204-1: 2016	BS 8611:2016	EN ISO 9241-129:2010	EN 62264-1:2013
EN 614-2:2000		EN ISO 9241-161:2016	EN 62541
EN ISO 11161:2007		EN ISO 9241-210:2010	EN 62714-1:2014
EN 842:1996 +A1:2008		EN ISO 9241-303:2011	
EN 981:1996+A1:2008		EN ISO 9241-400:2007	
EN 894-1:1997+A1:2008		EN ISO 9241-410:2008	
EN 894-2:1997+A1:2008		EN ISO 9241-920:2009	
EN 894-3:2000+A1:2008		EN ISO 6385:2016	
EN 894-4:2010		EN 10075-1-2000	
EN 1005-2:2003+A1:2008		EN ISO 14915-1:2002	
EN 1005-3:2002+A1:2008			
EN 1005-4:2005+A1:2008			
EN ISO 14738:2008			

Although this list may need amendment or extension over the course of the project, the review has produced an initial assessment that should assist the development of use case designs and guide the identification of gaps between current requirements and those that will be needed to cover the A4BLUE systems comprehensively.

4 BETA PHASE USER REQUIREMENTS CAPTURE

4.1 USER LEVEL REQUIREMENTS SURVEY

The purpose of this activity was to obtain a broader understanding of the likely requirements of global users of the A4BLUE work system solutions via a survey. Additionally, it was intended to validate the findings from the Alpha phase, by identifying any similarities and differences between what A4BLUE partners identified as the key design priorities that should be incorporated in the design of A4BLUE use cases, and the priorities of individuals external to the A4BLUE project.

4.1.1 SAMPLE

The purpose of this survey was to gather a more comprehensive account of the user requirements for future manufacturing systems therefore, a larger broader sample was needed compared to the Alpha phase. Partners were asked to disseminate the survey as widely as possible both within their organisations, externally to contacts outside of manufacturing, and on social media platforms. To take this wider population into account, two additional user groups were included in the Business User group: "Administration" and "Sales". Table 14 presents the number of participants obtained across each of the user groups.

Table 14 : Beta Participant Representation for Each User Group

User groups		Frequency	Total Frequency
Business	Finance / accounts	1	4
	Cost engineering	1	
	Marketing	1	
	Customer service	0	
	Legal	0	
	Administration	1	
	Sales	0	
Organisation	Senior management	0	1
	Production manager / supervisor	1	
	Operator (shop floor)	0	
	Maintenance (shop floor)	0	
	Trade union	0	
Technical	System design / architect	3	18
	Technology acquisition	1	
	Technology / system integration	8	
	IT	2	
	Life cycle engineering / management	2	
	Assembly planning	2	
Human	Occupational health	0	2
	HR	0	
	EHS	0	
	Ergonomics / human factors	2	
	Training and Development	0	

The greatest frequency of participants was from the Technical user group category, the same results were obtained during the Alpha phase. The lowest number of respondents were from the Organisation user group, whereas in the Alpha phase the smallest user group was the Business group. Two participants identified with more than one user group, the user groups identified were all in the Technical group. One participant indicated that they were part of "Information technology", "Life cycle engineering / management", and "Technology / system integration"; the second participant chose "Information technology", and "System design / architect" to describe their job role. Had participants been forced to return a single response the Technical group would have still remained the largest. Once again, these results likely reflect the companies that comprise the A4BLUE consortium and the contacts they have, additionally it is likely that those who work in the Technical user group will have a greater interest in the development of new manufacturing systems, this is further reinforced by the largest number of participants who described their job role as "Technology / system integration".

Overall the spread of responses from different job roles could have been better indicating that the survey has not captured the range of user requirements that are important for the A4BLUE solution across future user groups. 11 groups did not receive any contributions: "Customer service", "Legal", "Sales", "Senior management", "Operator (shop floor)", "Maintenance (shop floor)", "Trade union", "Occupational health", "HR", "EHS", and "Training and Development". Furthermore, fewer participants completed the survey compared to the Alpha phase, a reason for this may have been the targeted direct contact proposed to partners and the profiles of users subscribed to the A4BLUE dissemination channels. Further, possible explanations are detailed in Section 4.1.2.6. However it should be noted that the participants for the Alpha phase were restricted to the four use case scenarios involved in A4BLUE, the participants for the Beta survey were external to the A4BLUE consortium and therefore their responses are likely to be more diverse and based on their experience and the companies that employ them.

4.1.2 SURVEY DESIGN AND DATA COLLECTION

4.1.2.1 Topics

The topics developed for the Alpha survey were reviewed and updated to remove redundancy in the topics and their items. Table 15 presents the Alpha and adapted Beta topics, to clearly show where changes were made from one phase to the other. "System Information and Instructions" was removed in the Beta phase as it overlapped with "System Feedback and Assistance" which was updated to "Work System Feedback, Training and Assistance" to ensure the topic clearly detailed the items covered within it.

Table 15 : Alpha and Beta Topics

Topics	
Alpha	Beta
Organisational Requirements	
Automation and Robotics	
Communication and Interaction Mechanisms	
System Feedback and Assistance	Work System Feedback, Training and Assistance
System Information and Instructions	
System Security and Data Management	

4.1.2.2 Format Design

The format of the questions in the Beta survey did not change from the Alpha survey and are detailed in Section 3.1.3.2. The instructions and the information pages were simplified to a single page in the Beta survey. Changes to the questions and their items are detailed in Section 4.1.2.3 below.

4.1.2.3 Items / Questions

The layout of the questions did not change from the Alpha phase, both qualitative and quantitative questions were retained. The Alpha phase items were reviewed and updated. The first stage involved reviewing the suggested items made by participants from the Alpha phase and adding any suitable items to the survey. Next, all items across the topics were then reviewed, overlapping items were removed, complex items were simplified, and each item was checked to ensure it measured a single specific and relevant factor. This ensured the accessibility of the items and prevented any confusion over what potential feature of future manufacturing systems participants were responding to.

4.1.2.4 Translations

The time limitations experienced for the Alpha phase were experienced during the development of the Beta phase survey, therefore it was not possible to complete a multi-stage translation process. The translation process used in the Alpha phase was repeated for the Beta survey. The protocol that was followed entailed: sending the completed survey to partners (ENG, RWTH, Airbus, TEK and CESA) to translate, once the translations were returned they were uploaded on to EUSurvey. Partners (TEK, ENG, RWTH, Airbus, and CESA) reviewed the uploaded translated surveys to check that the translations were accurate and to look for any translation errors. The partners contacted the Cranfield Researchers detailing any changes required, and updates were made to the survey.

4.1.2.5 Ethics

The development and administration of the User Requirements Survey was performed in accordance with the regulations and approval of the Cranfield University Science and Engineering Research Ethics Committee (SEREC). The instructions and format of the survey was designed to ensure ethical issues were covered, such as informed consent, anonymity, data withdrawal, etc.

4.1.2.6 Survey Administration

Once all translated surveys had been completed and uploaded to EUSurvey, the link to the survey was disseminated to all partners within the consortium. These partners were then asked to distribute the survey as widely as possible; forwarding the link on to contacts in the manufacturing industry, individuals in other sectors (e.g. automation and technology developers), and anyone in the general public who may have provide insight to the development of new manufacturing systems. The link was distributed on social media websites LinkedIn and Twitter, posted on company websites, and emailed to contacts. As can be seen in Section 4.1.1 there were fewer respondents than in the previous phase. Wide distribution of the link required participants to forward the link on, this requires time to build momentum therefore, more time may have been required for data collection. A further contributing factor for the lower participant numbers is a limitation of EUSurvey; a participant provided feedback on the platform stating that they had been unable to submit their survey due to their organisations corporate firewalls. Therefore, it is possible that other potential participants had the same problem.

4.1.3 ANALYSIS

It was not possible to conduct a more investigative statistical analysis due to the small sample size and spread of participants across the user groups. The summaries are presented below, in the order they were presented in the survey, the percentages and frequencies for each item can be found in Annexes

I to M. As detailed in the Alpha phase, the overall degree to which participants agreed with items was calculated by adding together the scores that were rated as "Essential" and "Desirable" and calculating the percentage. These overall agreement scores can be found for each item in the Annexes (I-M) to this report.

To identify the items participants considered to have the highest priority key user requirements were additionally identified. First the "Essential" items were isolated, and ordered based on number of "Essential" responses. If two items had the same number of "Essential" responses the number of "Desirable" responses were identified and used to identify the order of the items. The same method was used to rank the "Desirable" responses. These ranked items can be found in Section 4.1.5.

4.1.4 RESULTS

4.1.4.1 Biographical Data

4.1.4.1.1 Age and Country of Participants

Twenty-two participants completed the survey from a range of companies, provided their age and the country they worked in. Figure 12 shows that the greatest percentage of participants were in the 26-35 group (45 %), the greatest percentage of participants who completed the Alpha survey were also between these ages however the percentage was slightly less (42%) (Figure 6). The age range with the lowest number of participants was 56-65 with only a single participant. Once again there were no participants in the over 65 age range.

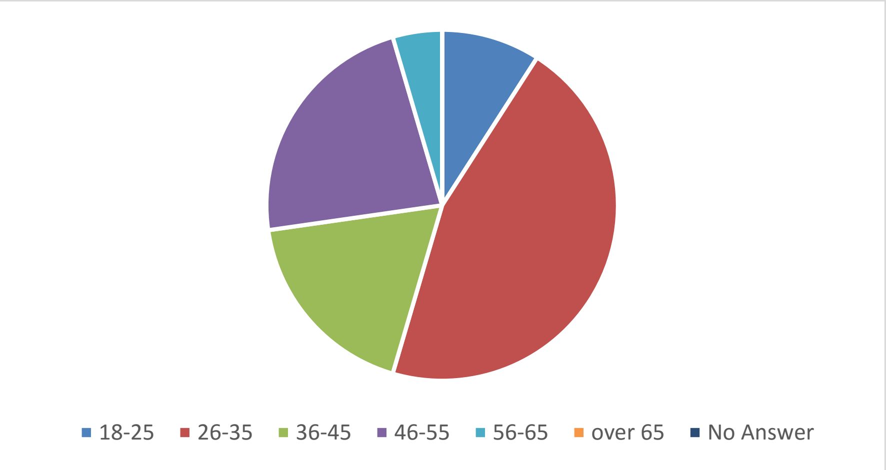

Figure 12: Beta Participant Ages (%)

Figure 13 presents the countries that participants work in. The largest percentage were from Germany (41%), and the smallest from Mexico (5%). The UK, German, Italian, and French responses are to be expected because this is where five of the A4BLUE consortium are based and their marketing is likely to have reached individuals within their countries. There were no participants from Spain which was unusual because the largest number of respondents who had taken the Alpha survey had been Spanish.

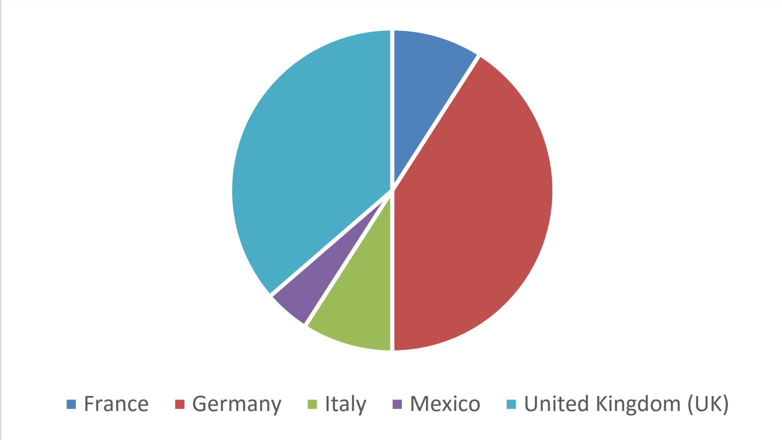

Figure 13: Country in Which Beta Participants Work (%)

4.1.4.1.2 Industry

Participants were asked to choose which industrial sector they work in, all provided a response. The majority of participants work in "Aerospace", whereas "Manufacturing" and "Research" had one participant each. This question was changed from the Alpha survey from a focus on manufacturing to include all industries, because the survey was marketed more broadly. There were thirty-nine items in this question however, participants only work in the six industries presented in Figure 14. The single participant that indicated they work in "Research" additionally indicated that they work in "Science". It is unclear which field of science and research participants work in and future surveys should look to include an option to specify if these sectors are chosen.

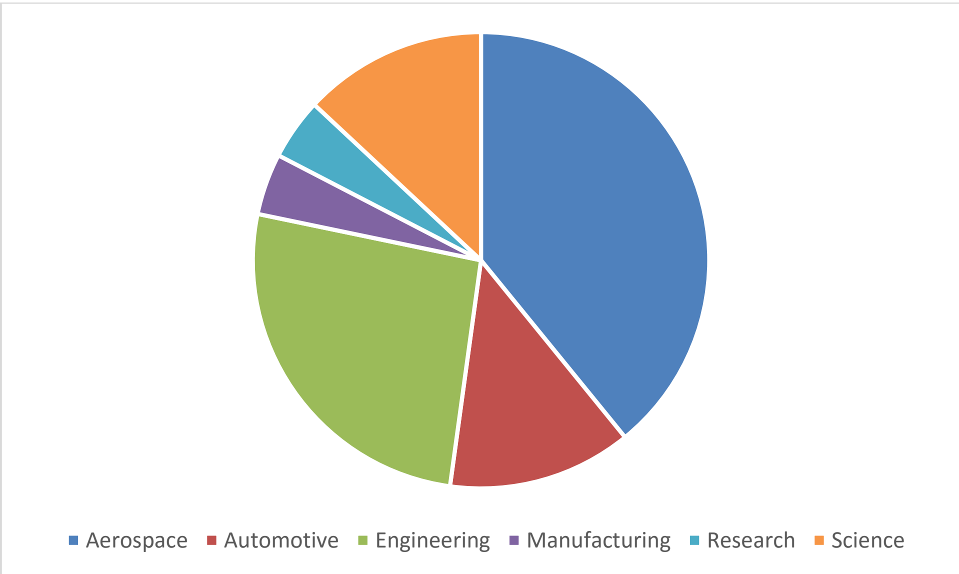

Figure 14: Industrial Sector (%)

4.1.4.2 Response Profile

All twenty-two participants completed the "Organisational Requirements" questions, four participants missed one item and one missed two items. This Topic has the greatest number of participants that missed items, it is difficult to identify why this has occurred because out of the 6 missed items there was only one item: "On-the-job work instructions for workers" which more than a single participant did not respond to. The rest of the topics only had one or two missed items: “Automation and Robotics” two missed items, “Communication and Interaction Mechanisms” one missed item, “Work System Feedback, Training and Assistance” one missed item, and “System Security and Data Management” had two missed items.

One participant dropped out of the survey after completing the “Organisational Requirements” section, a second participant did not continue after the “Automation and Robotics” topic, and a third participant dropped out of the survey after completing the “Work System Feedback, Training and Assistance” section. These participants did not provide their contact details, so it is not possible to query why they did not complete the survey.

4.1.4.3 Organisational Requirements

Participants were asked to consider items under the topic “Organisational Requirements” and identify whether they felt each item was “Essential”, “Desirable”, or “Unnecessary” with regard to “Assembly work systems of the future”. All items except one were identified as “Essential” or “Desirable”, with overall agreement scores ranging from 100% to 77% (“overall agreement” the sum of responses for both “Essential” and “Desirable” responses). Twenty-two out of the twenty-five items had a greater than 80% overall agreement. The items with 100% “overall agreement” scores were:

- Constant recording of automation / robot usage data to a central system to manage maintenance activities
- Systems that can detect and adjust to suit the requirements of different operators e.g. training and experience levels

The greatest “Essential” responses were returned for:

- Continuous data collection for analysis of system performance and optimisation needs (73%)
- Monitoring work station performance for future process improvement (73%)
- Constant logging of production waste data for the purposes of future planning (68%)

Highest “Essential” low seventies which shows a variation in how the participants prioritised the items compared to the Alpha survey. This may be as a result of the change in who completed the survey and from the simplification of the items. One of the items with a 100% “overall agreement” and highest “Essential” responses mostly covered logging and monitoring data within the workplaces, either for improvement, or optimisation. The second items with 100% “overall agreement” and three of the highest “Desirable” responses bulleted below cover adaption of future work systems to the worker. These findings suggest that participant’s priority is with improved system capability for production purposes, with adaption to human operators following.

- Ability to assess and adapt to optimal levels of automation for individual workers (68%)
- Abilities for determining optimal levels of automation to maintain operator satisfaction (64%)
- Capabilities for evaluating workers’ levels of satisfaction (64%)
- Self-adjusting to compensate for reduced technical capabilities, e.g. older technologies, functional (64%)

A single item had a high “Unnecessary” score. This reinforces the responses highlighted above where the work systems should be adaptable. It should be noted however that the score was a very close split with 32% for both the “Essential” and “Desirable” responses.

- Workstations that provide the same information to all workers (36%)

A single participant provided a comment, this covered the survey design rather than explaining their response to the items within the topic. The “Unnecessary” response option was intended to cover rejection of items, however this comment suggests that a stronger response may be necessary.

“I miss the category "to be rejected" in this survey”

Participant 10

Participants were asked to provide additional item suggestions. Nine participants chose to do so with two with four participants providing additional items, these are presented below in Table 16. Three of the suggestions cover automation and robotics, indicating the awareness people have of robotics and automation and the complexities of their introduction into future manufacturing systems.

The suggestions covering human machine interfaces, wearable smart devices, adaptive and personalised systems are covered in the later topics: “Communication and Interaction Mechanisms” and “Work System Feedback, Training and Assistance”. Two suggestions were directly linked to data protection, the suggestion made by participant 7 which proposes performance reports of each operator would require data protection consideration and may not be suitable as it may lead to problems with operator moral and acceptance of new technology. This is reiterated by the suggestion made by participant 10 regarding the consideration of data anonymization at the start of the development process.

Table 16 : Beta Participant Suggestions for Assembly Work System Features: Organisational Requirements

Participant	Suggestion	Translation	“Essential”/ “Desirable”
1	*“in a scenario that foresees a massive and pervasive use of robots and automation, it is important to create a good balance on the workplace, encouraging relationships among people and creating "islands of relationship"*		Essential
3	*“A clear understanding of where the automation will replace human skills and the implication to the use of human skills - done correctly this should 'up skill' the human aspects of the assembly work system”*		Essential
4	*“User-specific (Skill specific) HMI”*		Desirable
	“Connectivity via wearables / Smart devices (Phones, Tablet, ...)”		Essential
	“skill needs and skills of the assembly System to be provided for operative planning”		Essential
7	*« présentation (par exemple trimestrielle) des bilans de performance aux opérateurs pour chaque poste »*	Charts (for example quarterly) of performance reports, to the operator for each workbench	Essential
	« veille technologique permanente au niveau des opérateurs sur les améliorations de poste »	Permanent Technology watch, to the operators, on the improvements of the workbench	Essential

Participant	Suggestion	Translation	"Essential"/ "Desirable"
10	*"We need systems that anonymize collected data and provide strong guarantees with respect to privacy. This apsect is seldom considered right from the beginning, yet has massive impact on the global system architecture. More emphasis on this topic, please."*		Essential
11	*"Machines and Processes need to be adapted to the individual worker as much as possible."*		
15	*"Feeback loop to ensure that the operations are carried out properly"*		Desirable
	"Integration with PLM"		Desirable
16	*"Ability to reduce Information to a manageable minumum (only provide relevant data, incl. option to serve more details if required)"*		Essential
	"Ability to allow operator to select individual automation level (personalized configuration ; to anticipate acceptance in collaboration with intelligent Systems; operator can increase Automation level autonomously in the way he feels more comfortable with the system (e.g. learning path in collaboration)"		Desirable
17	*"Direct Customer Linkages: Requirements, Satisfaction, Future Load"*		Desirable

4.1.4.4 Automation and Robotics

Within this topic participants were presented with items that cover automation and robotics. Overall agreement for the items ranged from 64% to 95%, all items had either a majority response for either the "Essential" or "Desirable" options. The greatest "Essential" response was returned for the items bulleted below. Both cover safety considerations during operator interactions with the robots and automation. This shows the criticality safety has for participants, particularly as these responses reflect those from the Alpha survey (Section 3.1.5.3). Therefore, safety should be a priority in the design of future manufacturing systems.

- Collision avoidance detection and stop functions (77%)
- Mechanisms that alert operators of safety status and functioning (73%)

The items with the greatest percentage of "Desirable" responses were:

- Adaptability of position and configuration to suit operators' physical characteristics, e.g. height, reach (68%)
- Mechanisms for maintaining operators' awareness of process status (64%)

- Automatic detection of workforce / operator profiles (55%)

Where the “Essential” response profile highlights the need for safety. The “Desirable” responses show the importance of a system that adapts to the operators and keeps them informed of changes. There were no items in this topic that had “Unnecessary” responses greater than the “Essential” and “Desirable” responses. Therefore, indicating that all items included within this topic should be considered in the design of automation and robotics in future manufacturing systems.

One participant chose to prove the additional comment below. This comment reiterated the criticality of safety systems particularly during human robot collaboration, this reinforces the response profile seen for the items with the highest “Essential” scores.

“In a collaborative environment the safety systems are fundamental - without them the system will not be acceptable for use”

Participant 3

Participants were also asked to provide item suggestions, no participants chose to provide additional suggestions about “Automation and Robotics” in the design of future assembly work systems. It is possible that if the participant pool was larger suggestions may have been made.

4.1.4.5 Communication and Interaction Mechanisms

Participants were asked to review items under the topic “Communication and Interaction Mechanisms” and select whether they felt the item was “Essential”, “Desirable”, or “Unnecessary”. The overall agreement (addition of “Essential” and “Desirable” percentages) response profile for “Communication and Interaction Mechanisms” were greater than 50%. There was a single item that had a greater response for the “Unnecessary” choice:

- Defined voice command interaction systems (with limited standardised vocabulary and command options) (36%)

This is response reflects that other items covering voice interaction mechanisms using alternative modes of speech were scored as “Desirable”. Therefore, it is possible that participants felt that their positive response for alternative modes of interaction made this item “Unnecessary”.

The items with the greatest “Essential” percentage scores were:

- Feedback mechanisms that show if the system has understood a command (64%)
- Visual display of messages to operators providing text or graphic notifications / work instructions (59%)
- Mechanisms for operators to provide feedback on process / task status (55%)
- Interaction capabilities that enable real-time query-response communications(55%)

The importance of visual feedback remains as important as it did in the Alpha responses (Section 3.1.5.4). The other items indicated as “Essential” by participants cover interaction with systems and the ability for the operator to provide feedback. These items are key to evolvable systems and ensuring clear communication between man and machine, and operators and their management and other operators. This is further reinforced by the “Desirable” score for enabling operators to share practices and problem solving in the bullet point below.

The “Desirable” items had higher response percentages than either the “Essential” and “Unnecessary” options. The same was found for the Alpha survey, the highest scores were given for the items below:

- Adaptable systems where workers can choose the mode of interaction they use (68%)
- Speech / voice messages to operators for providing auditory notifications / work instructions (64%)

- Mobile devices for communications and receiving notifications(59%)
- Mechanisms for operators to share practices/ problem solving solutions informally (59%)
- Wearable control devices (59%)

The importance of wearable and mobile technology can be taken from these scores and is reinforced by the suggestion of including this technology made by Participant 4 in the "Organisational Requirements" Section (4.1.4.1.4). The scoring of these items as "Desirable" rather than "Essential" indicates participant awareness that the introduction of these devises may not be possible, but a benefit is seen from introducing them.

Participants were asked to give additional comments that may have about their selection. Participant 3 chose to include a comment, and details important considerations for adaptable systems that require consideration.

"Understanding the status / configuration of the automation / robotics will be important to ensure the operators know what they are working with and can understand the systems behaviours - however, reconfiguring the system for a new task or thr preferences of a specific operator will need to be done quickly (not practical to spend half a shift setting the kit up) - also what happens when the system is configured for a different operator and behaves differently to the way the active operator is expecting?"

Participant 3

Participant 3 also provided an item suggestion, they did not identify whether the item was "Essential" or "Desirable". This may be because the suggestion is not a suggestion but more a recommendation on how to introduce wearable and mobile technology and the need to have a clear justification for their introduction and use.

Table 17: Beta Participant Suggestions for Assembly Work System Features: Communication and Interaction Mechanisms

Participant	Suggestion	"Essential"/ "Desirable"
3	*"Many of teh 'interaction' topics are relevant and necessary to ensure the automation is working in a way operators understand and can manage - but there is the potential to over design the interface or use technology because we can (e.g. teh mobile or wearable items) - there needs to be a clear need and justification for each function that adds complexity to the system."*	

4.1.4.6 Work System Feedback, Training, and Assistance

The items within this section investigated participant's opinions regarding work system feedback, training, and assistance. Overall agreement for the items within this topic were between 64% and 91%, all items had a majority of either "Essential" or "Desirable" responses. The items with a majority of "Essential" scores included provision of assistance both automatic and standardised, automatic ergonomic assessment, feedback, and provision of tools (automatic provision and constant availability). The items with the highest percentage of "Essential" responses were:

- Assistance provided when requested by operators (68%)

- Personalised ergonomic assessment from the system to identify individual operator needs (59%)

Compared to the "Essential" items, those with a greater "Desirable" responses were those that included adaptive and novel technology. As seen in the Alpha results participants rated the use of augmented reality as more "Desirable" for the provision of remote assistance (59%), with training both VR and AR had the same percentage scores (55%), however the "Essential" scores were higher for AR (27%) than VR (23%) perhaps because AR training enables operators to remain on the shop floor and whereas with VR training would need to be completed off line.

Participant 3 provided the comment below, which reiterates their comment made in the previous Section and the need to carefully consider how novel technology is introduced to the shop floor and operators.

"Many of these topics are essential as a work system would not function without them. They happen in a 'manual' form on current work systems - design of an automated work system would need to understand the potential benefits that will be gained."

Participant 3

Participants chose not to provide additional suggestions about "Work System Feedback, Training, and Assistance" in the design of future assembly work systems.

4.1.4.7 System Security and Data Management

The responses from "System Security and Data Management" were more spread across the response options compared to the other topics. This is because the procedure of how to best treat personal information is evolving, as can be seen with the General Data Protection Regulations (GDPR) recently put into place by the EU.

The items with a greater number of "Essential" responses covered capture (68%) and analysis (68%) of systems performance data, these items were followed closely by Security both at the local level with the use of passwords for workstations (68%) and identify cards (45%), and from external attacks (59%); and how to capture operator data (equally across all workstations, 50%) and only personnel who maintain IT systems (36%) should have access to it. Reinforcing this the item covering whether managers should have access to personal data had a majority of "Unnecessary" responses from participants (45%). However, the responses indicate that it is "Desirable" for managers to be automatically provided with performance data.

The items with the higher percentage of "Desirable" responses mainly covered operator data, with operator profiles stored on the cloud (41%), held for a predefined limited period of time (43%). Furthermore, participant responses indicated that it was "Desirable" for operator data to only include ergonomic information (36%), this would ensure that systems were set to the right height and functioned at the correct speed for the participant. It was also "Desirable" for system data to be retained for a limited period of time (41%).

Participants were asked to provide comments to explain their responses to the items in the first question. Participants 3, 13, and 16 provided insight into their responses, they reiterate the importance of how operator data is handled and ensuring data security. The number of comments made by participants for this topic shows how important it is to ensure that data is protected and secure.

"Data collection is important. Personal data is already legally protected (Data protection etc.) The critical aspect is knowing what teh data will be used for and how it will drive definition of further

improvements. These is no point in gathering masses of data if it is only put into storage and not utilised."

Participant 3

"It heavily depends on what/how the stored data will be used and by whome. Assurances re data cybersecurity, management and usage will need to be an integral part of any potential devwlopmenta on this workstream. Otherwise it is difficult seeing this going through industrial relation consultations."

Participant 13

"Treatment of person related Information should be an individual subject according to local/ national defined rules"

Participant 16

Participant 16 provided three item suggestions, these are detailed in Table 17 below and were all marked as "Essential". The third item although reiterating some of the items in the topic, states that data protection should be defined within company policies. The other two items suggest that rules are developed more managing sensitive operator data and that these rules are used for all operators and workstations. It should be considered whether sensitive data should be captured by assembly work systems of the future, and whether it is possible to prevent the capture of any sensitive data.

Table 18: Beta Participant Suggestions for Assembly Work System Features: System Security and Data Management

Participant	Suggestion	"Essential"/ "Desirable"
16	*"it is important to apply common rules for sensitive data (individual profiles, personal data etc.)"*	Essential
	"the rules must be applicable for all Workstations and operators"	Essential
	"personlized data must be protected (defined in Company policies)"	Essential

4.1.5 SUMMARY OF BETA USER REQUIREMENTS CAPTURE

The User Level Requirements survey met its aim of capturing users' requirements for the design of new work systems. Twenty-two participants rated a range of design features "Essential", "Desirable", and "Unnecessary" across five categories: ***Organisational Requirements, Automation and Robotics, Communication and Interaction Mechanisms, Work System Feedback, Training and Assistance, and System Security and Data Management***. The user requirements are now listed and coded in order of priority ranking in the following 'Requirements Book' tables, additionally included is the Alpha code to enable cross analysis between the different requirements of the Alpha and Beta participants.

Table 19: User Requirements: Organisational Level

1. Organisational Level		
	ESSENTIAL	
Code		Description
Alpha	Beta	
1.1	2.1.1	Continuous data collection for analysis of system performance and optimisation needs
1.6	2.1.2	Monitoring work station performance for future process improvement
1.16	2.1.3	Constant logging of production waste data for the purposes of future planning
	2.1.4	On-the-job work instructions for workers
1.17	2.1.5	Constant recording of automation / robot usage data to a central system to manage maintenance activities
1.5	2.1.6	Constant recording of tool usage data to a central system to monitor maintenance activities
1.3	2.1.7	Reconfigurability for new automation or robotics, e.g. 'plug & produce' capabilities
	2.1.8	Automated systems and robots that operate in a standardardised way
1.8	2.1.9	Continuous interaction of all systems in the organisation for resource allocation
	2.1.10	Abilities for evaluating and selecting optimal levels of automation to meet economic requirements
	2.1.11	Automatic responses to answer manual requests from operators
	DESIRABLE	
	2.1.12	Ability to assess and adapt to optimal levels of automation for individual workers
	2.1.13	Abilities for determining optimal levels of automation to maintain operator satisfaction
1.19	2.1.14	Capabilities for evaluating workers' levels of satisfaction
1.15	2.1.15	Self-adjusting to compensate for reduced technical capabilities, e.g. older technologies, functional
	2.1.16	Functions that can adapt to suit new / different workforce requirements
	2.1.17	Systems that can detect and adjust to suit the requirements of different operators e.g. training and experience levels
1.7	2.1.18	Autonomous assessment of requirements and adaptation to new products
1.7	2.1.19	Autonomous assessment of requirements and alteration to new processes
	2.1.20	Capabilities that adapt to workers' levels of satisfaction
1.9	2.1.21	Automated system or robot capabilities for utilising operators' expertise/ knowledge
	2.1.22	Direct connection to organisational systems for post-production product service and support
1.4	2.1.23	Direct connection to internal control systems (e.g. Enterprise Resource Planning) to adapt the assembly process
	2.1.24	Standardised off the job training for all workers

Table 20: User Requirements: Automation and Robotics

2. Automation and Robotics		
	ESSENTIAL	
Code		Description
Alpha	Beta	
2.1	2.2.1	Collision avoidance detection and stop functions
2.10	2.2.2	Mechanisms that alert operators of safety status and functioning
	2.2.3	Automatic updates on information concerning process / production
	2.2.4	Mechanisms for making operators aware of safety status
	2.2.5	Automatic feedback to operators of updates to process / production information
2.12	2.2.6	Autonomous adaptation to varying production demands
	2.2.7	Mechanisms for providing information when requested by operators
2.3	2.2.8	Autonomous detection and adjustment of speed to suit the distances and / or speeds of operators
2.14	2.2.9	Autonomous adaptation to varying environmental conditions, e.g. light and noise levels
	2.2.10	Standardised system programs / consistent behaviour, e.g. speed, procedure
	DESIRABLE	
2.8	2.2.11	Adaptability of position and configuration to suit operators’ physical characteristics, e.g. height, reach
	2.2.12	Mechanisms for maintaining operators’ awareness of process status
	2.2.13	Automatic detection of workforce / operator profiles
2.5	2.2.14	In-built functions to enable collaborative work (on shared tasks) with operators without physical guarding
	2.2.15	Ability to distinguish people from other system features and adapt behaviour
	2.2.16	Personalisable functions to satisfy individual operators’ preferences, e.g. working methods, speed etc.
	2.2.17	Manually controllable functions that can be used by operators
	2.2.18	Autonomous detection and adaptation of functions in response to workers characteristics, e.g. skill, age, experience
2.18	2.2.19	In-built functions to enable co-existing work (on separate tasks but near to an operator) without physical guarding
2.17	2.2.20	Automatic feedback to management on process status / task completion
	2.2.21	Functions for teaching workers how to perform tasks
	2.2.22	Autonomous adaptation of programs to correspond with operators’ capabilities and preferences

Table 21: User Requirements: Communication and Interaction Mechanisms

3. Communication and Interaction Mechanisms		
	ESSENTIAL	
Code		Description
Alpha	Beta	
3.1	2.3.1	Feedback mechanisms that show if the system has understood a command
	2.3.2	Visual display of messages to operators providing text or graphic notifications / work instructions
	2.3.3	Mechanisms for operators to provide feedback on process / task status
	2.3.4	Interaction capabilities that enable real-time query-response communications
	2.3.5	Interactive systems that enable operators to interrogate information / instructions more deeply when needed
	2.3.6	Interactive systems that allow operators to control functions and automation / robots
	2.3.7	Mechanisms for operators to report personal circumstances and concerns
	DESIRABLE	
3.11	2.3.8	Adaptable systems where workers can choose the mode of interaction they use
	2.3.9	Speech / voice messages to operators for providing auditory notifications / work instructions
	2.3.10	Mobile devices for communications and receiving notifications
	2.3.11	Mechanisms for operators to share practices/ problem solving solutions informally
	2.3.12	Wearable control devices
3.6	2.3.13	Systems that can be controlled using handheld mobile devices, e.g. tablet, smartphone
3.5	2.3.14	Combined visual and auditory messages for feedback and notifications
	2.3.15	Wearable devices for communications and receiving notifications
	2.3.16	Interactivity that enables operators to verify each completed task step / retrieve information on the next step
3.3	2.3.17	Fixed / static controls, e.g. mounted console / tablet
	2.3.18	Traditional computer based format for providing work instructions
3.10	2.3.19	Gesture control interaction systems
	2.3.20	Augmented reality devices that provide controls, e.g. ‘Google glasses’
	2.3.21	Personalisable communication devices for sending / receiving individual updates and information
3.4	2.3.22	Non-defined voice command interaction systems (using natural speech with unlimited vocabulary)

Table 22: User Requirements: Work System Feedback, Training and Assistance

3. Work System Feedback, Training and Assistance		
	ESSENTIAL	
Code		Description
Alpha	Beta	
4.10	2.4.1	Assistance provided when requested by operators
	2.4.2	Personalised ergonomic assessment from the system to identify individual operator needs
4.11	2.4.3	Automatic detection of / guidance for emergency and/or unexpected situations
	2.4.4	Standardised assistance and guidance provided by the system to suit all operators
4.9	2.4.5	Mechanisms for operators to directly input knowledge and process improvement ideas
	2.4.6	Provision of specific feedback when requested by operators
4.2	2.4.7	Constant availability of tools and equipment
	2.4.8	Automatic provision of tools / equipment when system detects need
	2.4.9	Generic ergonomic / postural guidance from the system
	DESIRABLE	
4.4	2.4.10	Augmented reality devices to provide remote assistance from other personnel / more experienced operators
	2.4.11	Automatic provision of assistance when system detects ergonomic needs of an operator
	2.4.12	Automatic assessment of operators’ levels of satisfaction
	2.4.13	Augmented reality training methods that provides off- and on–the-job training for operators
	2.4.14	Tools / equipment provided bit the system in response to specific requests from operators
4.6	2.4.15	Personalised assistance provided by the system to suit operators’ individual capabilities
5.8	2.4.16	Virtual reality simulation training methods to develop operator competencies ‘off–the-job’
	2.4.17	Automatic detection and provision of assistance
4.1	2.4.18	Provision of tools / equipment at specific stages of assembly via system monitoring of progress
5.7	2.4.19	Augmented reality that provides information and instructions to workers while they are working
	2.4.20	Feedback from the work system to keep operators aware of overall system performance
	2.4.21	Feedback from the work system that keeps the operator aware of their own work progress
	2.4.22	Provision of ergonomic training from the work system
	2.4.23	Assistance / feedback from the system to keep operators satisfied as they work
	2.4.24	Continuous automatic feedback from the system

Table 23: User Requirements: System Security and Data Management

4. System Security and Data Management		
	ESSENTIAL	
Code		Description
Alpha	Beta	
	2.5.1	Systems automatically capture system performance data
	2.5.2	Systems automatically analyse data
	2.5.3	All workstations are password protected
6.1	2.5.4	Security mechanisms are required to prevent attacks from external sources
	2.5.5	Data is captured equally across all workstations and roles
	2.5.6	Identity cards are needed for operators to log on before using a workstation
6.2	2.5.7	Managers to have access to system data (on process, performance, etc.)
6.2	2.5.8	System data (on processes, performance, etc.) can be accessed by information technology maintenance personnel
	2.5.9	Access to operators' personal data is only available to personnel who work on the maintenance of information technology systems
	2.5.10	Systems automatically capture individual operator performance data
	DESIRABLE	
	2.5.11	Systems automatically report performance data to managers
	2.5.12	Operator data is retained for predefined limited period of time
	2.5.13	System data is retained for a predefined limited period of time
	2.5.14	Operator data for all workers is kept on the 'cloud' so that individual profiles can be downloaded when they log on to a workstation
	2.5.15	Data is only be captured / retained for specific operators / specific workstations
6.4	2.5.16	Operator data only includes ergonomic information, e.g. the height they set the workbench

4.2 BETA PHASE HIGH LEVEL REQUIREMENTS REVIEW

The Alpha phase review of 'high level' requirements in Section 3.2 set out a range of formal technical and ethical / legal obligations for the design of new production systems in the European Union, primarily consisting of harmonised European performance and safety standards. This section presents the Beta phase follow-up review of the high level requirements relevant to A4BLUE, which focuses on the ***design*** of new industrial systems (not shop floor system integration or wider organisational issues) and their ***assimilation*** of technologies (not the design of individual technologies' design which is assumed to be covered by specific laws and standards). Whilst most of the laws and standards cited in Section 3.2 remain unchanged or little changed, there are new revisions and additions to legislation and standards to include in this Beta phase update.

4.2.1 Laws

The Alpha phase review of high level requirements explained that whereas standards provide the technical requirements for safety and / or performance laws are typically developed to enforce long term policy. As described above, A4BLUE needs to comply with legislation governing safe system design and technology assimilation in new machinery / equipment. The legal requirements for the design, construction and supply of new machinery to be marketed in the European Economic Area is currently encompassed within the European Machinery Directive (2006/42/EC). However, the acceleration of technological advances in recent times has meant that there has been an emergence of activities to develop new laws for robotics, artificial intelligence (AI) and related digital technologies that are likely to become requirements for A4BLUE systems: for a) ethics and b) personal data protection.

4.2.2 Ethics

As described in the Alpha phase review, ethical requirements for the design of advanced technologies have not previously been a significant or explicit part of legislation. It is now only a growing concern in response to the salient rise in AI and robotics – which are the current primary focus of recent initiatives.

The 2012-2014 European Commission 'Robolaw' Project[1] was commissioned to review requirements for legislation, regulations and guidelines for future robotics. It concluded that a number of core principles needed to be considered for the requirements of manufacturers, consumers and industry / business including that:

- The design of robot systems must protect human dignity, safety and privacy
- Research and innovation must be accountable for applications and potential *dual use*
- Responsibility for robot actions and behaviours needs to be established.

In 2016 the European Union's Committee on Legal Affairs proposed that action is now needed to address the legal and ethical issues raised by new technologies, particularly AI and robotics, and civil laws are currently still under debate; this document will be updated as and when new law arrives. However, it is already clear that a key component of forthcoming law will be new consideration of ethical requirements in addition to traditional interests in safety and performance. Associated developments in standards covering ethics are also in progress and discussed below in section 4.2.2.

[1] Regulating Emerging Robotics Technologies in Europe: Robotics facing Law and Ethics (http://www.robolaw.eu/).

4.2.3 GDPR

Intelligent robots and digital technologies are often capable of collecting a great deal of data and even if this aspect of design is intended for good and ethical purposes there is always a potential risk that such data may be used for unintended or unethical motivations. There have been rising concerns about whether current legislation sufficiently covers potential risks that are emerging as a result of new technology and its data collection capabilities. In the EU, the Data Protection Act 1998 (DPA) remains the safeguarding directive but this applies only to the processing of personal data, i.e. any operation related to an individual's information from which they can be identified (e.g. data collection, storage, dissemination and deletion). However, to address the emerging greater requirements for new technologies the DPA is about to be replaced imminently with the General Data Protection Regulation (GDPR) (Regulation (EU) 2016/679) which is intended to simplify and unify EU regulations to enable international compliance. The GDPR will include a number of new or extended clauses to widen coverage and individual rights, such as: wider scope of responsibility including data suppliers / processors and export of data outside the EU, wider definition of what constitutes personal data, more inclusive thresholds for processing and accountability, a new legal requirement to report data breaches, tougher sanctions for non-compliance, and for organisations found guilty to apply governance data protection officers.

For the design of new systems with robotic and digital technologies that will collect and/or apply personal data it is recommended that the full GDPR which comes into force on May 25th, 2018 is reviewed: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R0679&from=EN.

In the meantime, a summary of the key clauses and impacts that will impact on A4BLUE are as follows:

- The GDPR will apply to 'controllers' (who define or decide the purposes and means of processing personal data) and 'processors' (who conduct operations or processes with the personal data on behalf of a controller).
    - In terms of the project's research design, A4BLUE partners who conduct human participant studies are unavoidably in both of these roles as they are defining and deciding research purposes and means of processing participant data but also processing it.
- The GDPR applies to 'personal data' which constitutes any information relating to a person who can be identified directly or indirectly (e.g. using coding)
    - In the A4BLUE project 'personal data' is ANY data derived from human participants and system users, e.g. their satisfaction, their profile characteristics, etc., regardless of whether we de-identify it using coding methods.
    - A4BLUE must make clear to participants, before they sign the Informed Consent and take part in any activities, how their personal data will be used and processed. This includes advising them that their data will be applied to create a behavioural / satisfaction model that may be applied to data from other users in the future.
- The GDPR requires that personal data is
    a) processed lawfully, fairly and in a transparent manner
    b) collected for specified and legitimate purposes and not further processed further for other purposes
    c) adequate, relevant and limited to what is necessary for the intended purposes
    d) accurate and, where necessary, kept up to date to maintain accuracy with regard to the intended purposes or erased / rectified without delay
    e) kept in a form which permits identification of data subjects for no longer than is necessary
    f) processed with appropriate security, including protection against unauthorised or unlawful processing and against accidental loss, destruction or damage

- There must be a valid lawful basis for processing personal data based on at least one of the six available lawful bases:
    a) Consent: the individual must give clear and unambiguous consent for their personal data to be processed for a specific purpose (an opt-in) and for distinct processing operations that are separate from other terms and conditions. Consent must not be as a result of default measures (e.g. pre-ticked opt-in boxes). The individual must be informed of their rights to withdraw consent and provided with simple methods by which they can do so. Existing consents and mechanisms need to meet the GDPR standard.
    b) Contract: this basis is relevant if data processing is necessary within a contract that the individual holds, or because they have asked for specific steps to be taken prior to a contract.
    c) Legal obligation: the data processing is necessary to comply with the law (not including contractual obligations)
    d) Vital interests: data processing is necessary to protect someone's life. Whereas this used to be relevant to only the individual themselves the new GDPR states that it is now important for anyone's vital interests to provide a basis for processing on this basis
    e) Public task: data processing is necessary for a task to be performed in the public interest or official functions; the new GDPR states that now the task or function must also have a clear basis in law
    f) Legitimate interests: data processing is necessary for legitimate interests, which under the new GDPR will also include those of a third party, unless there is a good reason to protect the individual's personal data which overrides those legitimate interests; it is also now important to document / record those interests

    - Any of these bases may be relevant to the application of A4BLUE systems in the future, after the project is completed and its results are disseminated. However, for the term of the project it is most likely that only the first basis (a) concerning 'Consent' will be required to justify personal data processing as it is relevant to standard requirements for human participant research.

- Data processing should be 'necessary', i.e. the same objective cannot be achieved without it
- The lawful basis should be determined and recorded prior to processing
- Privacy notices should include the identified lawful basis as well as the purposes of processing
- If purposes change, you may be able to continue processing within the original lawful basis if compatible (unless your original lawful basis was consent).
- If processing sensitive data (special category: genetic / biometric) a lawful basis AND an additional condition for processing this type of data is required

It is important to emphasise that the new GDPR will apply to every context and circumstance in which personal data is collected. Thus, for the A4BLUE project it governs how systems should be designed AND how the research being conducted in the development of those designs. To address how these new requirements need to be incorporated into system design, A4BLUE will incorporate activities in WP2 (i.e. task T2.4 Security risk assessment and secure middleware definition) to define the necessary GDPR specifications for system architectures and programmes that process personal data. Activities in WP3, WP4 and WP5 should follow the identified technical measures. Furthermore, the required organisational measures should be implemented in the framework of task T6.1 Experimentation site preparation. To address how these new requirements impact on A4BLUE research using human participants, activities will also be undertaken to identify new specifications for research protocols immediately as part of WP3 (for worker satisfaction and usability testing), and applied in the experimentation and evaluation work in WP6.

4.2.4 Standards

ISO standards are always assessed periodically, usually every five years, to consider whether a revision is required so technological advances are always a key factor in deliberations. In response to rising digitisation and automation there are initiatives to develop or extend safety standards, particularly for AI and robotics applications as in the legal world. To track revisions it is necessary to check the status and lifespan of each individual standards using information made public by the various standards bodies who are responsible for them, and it is even more painstaking to identify the production of any new standards as publicity may be unseen. Some key changes and developments that have been identified in the Beta phase of A4BLUE are now described.

- EN ISO 10218-2:2011 Robots and robotic devices — Safety requirements for industrial robots – Part 2: Robot systems and integration

In the Alpha phase review of high level requirements the first part of ISO 10218 (Part 1: 'Robots') was considered to not be relevant to A4BLUE system design on the basis that it deals with robot design from the robot manufacturer and supplier perspective. Instead, the second part was considered directly relevant (Part 2: Robot systems and integration) because the A4BLUE systems will be integrating existing COTS systems so the assemblage and installation requirements are important. In June 2016 the periodic revision of both parts of this standard were initiated by the responsible ISO Technical Committee Working Group (ISO/TC299/WG3 Industrial Safety) in order to address technological advances and growing developments in industrial human-robot collaboration. This revision intends to incorporate the topics covered in the technical standard that was published in 2016 as interim guidance for human-robot collaboration, TS 15066. The 10218 revision has now been extended by one extra year to a total of four years in order to accommodate the extent of work needed to cover both parts -1 and -2, with final publication now not due until May 2021. Although this is beyond the life of the A4BLUE project, and current progress is at an early stage, any parts of the revision that can be communicated will be updated in this document as the project proceeds.

- ISO/TS 15066:2016 Robots and robotic devices — Collaborative robots

As described, the contents of this technical standard (TS) will be absorbed into the current revision of ISO 10218 so although it will eventually be withdrawn it will, for A4BLUE, remain the most relevant standard covering collaborative applications for the duration of the project.

- EN ISO 9241 Ergonomics of Human System Interaction

The Alpha phase review identified a number of parts from the multi-component ISO 9241 series of standards may be relevant to A4BLUE. However, a new technical report (TR) is currently being developed by the responsible Technical Committee Working Group (ISO/TC 159/SC 4/WG 6 Human-centred design processes for interactive systems) which will also be of relevance to the project. The report TR 9241- Part 810: Robot intelligent and autonomous systems will specifically set out the state of the art in human-systems issues for Robot, Intelligent and Autonomous Systems (RAIS) that should be considered in the application of these technologies and priorities for future standardisation work. Developments will be updated in this document as they arise during the project.

Standards for other technologies being applied in the A4BLUE systems are being developed and updates should be included in D7.4 which will cover standards. For example, the new AR standard cited in the Alpha phase review remains under development: ISO/IEC 18039 Information technology — Computer graphics, image processing and environmental data representation and coding of audio, picture, multimedia and hypermedia information — Mixed and augmented reality (MAR) reference model. Additionally, a series of related ethical standards for robotics is currently under development within the IEEE's Global Initiative on Ethics of Autonomous and Intelligent Systems; there is also a possibility of other standards bodies adopting the only current ethical standard for robotics, BS 8611. Again, any publishable developments and information will be presented in D7.4.

5 HUMAN FACTORS BEST PRACTICE GUIDANCE

The Alpha phase high level requirements capture review described in Section 3.2 highlighted that one of the standards relevant to A4BLUE is the (EN) ISO 6385:2016 – Ergonomics principles in the design of work systems. This is because it provides a balance of human, social and technical requirements for the design of workspaces / workstations, work organisation, work tasks and environment, equipment and interfaces, etc. It is therefore a fundamental source of best practice guidance for human factors in the design of any new work systems, and in the A4BLUE project particularly useful in WP3 and WP4.

ISO 6385 sets out general principles as follows:

- Humans are the main factor and an integral part of the system, including process and environment, so major interactions between one or more people and the components of the work system, such as tasks, equipment, workspace and environment, shall be considered.
- These interactions create external work load which cause internal 'work strain' reactions depending on the worker's individual characteristics (e.g. size, age, capacities, abilities, skills, etc.) which will cause impairments (e.g. fatigue) or enablements (e.g. skill development): thus a feedback loop.
- Ergonomic system design aims to optimise work strain, avoid impairments and promote enablements.
- Ergonomics shall be applied at an early design stage rather than used as a preventive function to solve problems at a later stage. However, ergonomics can be successfully employed for redesign and in a risk assessment process where interactions between design and foreseeable behaviour should be considered to secure safety and health.
- In accordance with a human-centred and participatory approach, workers should ideally be involved in the design of work systems, including those responsible for constructing, maintaining, operating, and supervising.
- Work systems should be designed for a broad range of the target population and for people with special requirements to optimise accessibility, and a variety of conditions should be considered, e.g. normal, disturbed and degraded functioning.

ISO 6385 also sets out a series of phases that are typically involved in work system design, which require the application of appropriate methods from a variety of disciplines, as follows:

- **Formulation of goals (requirements analysis)**

It is important to identify the goals of system design (and redesign) as well as their requirements. For this, information regarding performance requirements and characteristics / requirements of the target workforce are required and ergonomic analysis is necessary to elicit human specifications which can be combined with technical specifications.

- **Analysis and allocation of functions**

When the new system requirements are identified, it is necessary to establish the functions which need to be fulfilled in order to meet these requirements and allocate these functions between worker(s) and equipment by analysing the capabilities and limitations of human and technical components and likely effects on human health, well-being and safety, as well as system performance.

- **Design concept**

When functions have been allocated to either humans or technical solutions an initial conceptual design for the work system (design concept) can be produced which shows the system structure and interactions between its components, developed with a human-centred approach. Functions that are allocated to workers should be transformed into a list of requirements for the design of tasks, jobs and work organisation. Functions allocated to equipment should be transformed into a list of demands for the design of work equipment, work tools (including software), workstation and work environment.

- **Detailed design (or development)**

Work system design should address independent components and interdependencies between them:

- *Work organisation*: the extent to which various work systems impact on each other, on workers, and on overall performance of wider organisational systems.
- *Work tasks*: function allocation to achieve the following goals:
    - that the task performance makes a significant contribution to the overall system and this can be understood by the people involved
    - that work tasks are identifiable as whole units of work rather than fragments
    - the experience and capabilities of the workforce are recognised
    - the application of an appropriate variety of skills, capabilities and activities is provided
    - people are given appropriate levels of autonomy for deciding priority, pace and procedure
    - opportunities are provided to develop existing skills and new skills with the work tasks
    - individual workers are not isolated from social and functional contact
    - worker overload and underload are avoided
    - repetitiveness and unbalanced work strain is avoided
    - sufficient meaningful feedback is provided to those performing the work task
- *Jobs*: designed to achieve system goals with appropriate demands on workers to optimise performance with combined factors of individual tasks, job content, workers' control and repetitiveness of operations. If an optimal level of demand is not achieved various methods shall be implemented to improve job quality, e.g.: breaks, activities / job rotation, job enlargement where individual workers are responsible for multiple tasks.
- *Work environment*: designed and maintained to minimise adverse effects of social, physical, chemical and biological conditions on worker health, safety and well-being, as well as on their capacity and willingness to perform tasks. Comprises physical, social, cultural and ethnic environmental factors. Wherever possible environmental factors should be controllable by operators and evaluations should be both objective and subjective.
- *Equipment and interfaces*: designed to consider psychological as well as physical and/or mechanical factors with interfaces that provide adequate information to allow rapid overview, information concerning detailed parameters, good visibility of controls and displays with their positioning made according to priority and functional grouping.
- *Workspace and workstations*: designed to allow people postural stability and mobility with a safe and stable base from which users can exert physical energy. Workstations, equipment and devices shall be designed to accord with requirements for body dimensions, posture, muscular strength and movement, and prevent fatigue from prolonged static muscular tension.

The sequence of design is flexible and may vary and iterations are normally required to achieve optimal solutions and may extend into periods of implementation and initial use.

- **Realisation, implementation, adjustment, verification and validation**

This phase involves the building, production or purchase of the new technical design of the work system and its installation in the place where it will be used. It must include careful introduction of the new system to all stakeholders, especially workers, and the provision of any necessary information and training. The initial period of use and adjustment should be considered the final design phase in which the necessary changes to improve system design and performance should be fully considered.

- **Evaluation and monitoring**

After realisation and implementation of the work system, it is necessary to conduct processes of evaluation and monitoring to obtain a complete overview of results and learn from them and to monitor effects to identify and prevent any negative impacts on user performance, safety, health, usability and cost-benefit. This will involve recording and analysing problems and experiences to develop any corrective, adaptive and preventive actions.

The general principles and phases of work system design that have been supplied in ISO 6385 provides a useful guide to designing new industrial systems within a human-centred approach. There are a number of additional standards which contain sections and clauses that may also be useful as guidance for human factors best practice in work system design, e.g. various parts of ISO 9241 Ergonomics of Human System Interaction.

Work performed as part of the EC FP7 TOSCA project (Total Operation management for Safety Critical Activities) in 2015 included a review of available standards and current industrial practices for incorporating Human Factors in work system design stage, including ISO 6385 and ISO 9241 (part 210: Human-centred design for interactive systems). This evaluation of gaps and issues led to a summary of areas for improvement [5], which are as follows:

1. Review education and training for engineers to include basic human factors for system design.
2. Integrate human factors principles within broader technical engineering and design standards.
3. Set up systemic reviews with end users in design processes and collect feedback from operations.
4. Structured risk assessment at design stage for operability and maintainability including analysis of issues related to processes and tasks for which the system is designed or connected to it.

The human factors best practice guidance for A4BLUE needs to include consideration of all of these factors, and the wider detail provided in the specified standards, to ensure human- / user-centred design.

6 CONCLUSIONS AND NEXT STEPS

Deliverable 1.4 presents the results of the Beta phase of T1.1 which is a refinement and development of the Alpha phase presented in D1.1. The User Level Requirements survey of the Alpha phase captured user opinions of fifty participants from the A4BLUE consortia on work systems to indicate the priorities that should be considered for systems design. The High Level Requirements capture of the Alpha phase that was first described in D1.1 version of this report focused on European laws and standards that appear to be most relevant to A4BLUE, to incorporate the formal obligations that impact on design and integration of technologies in new industrial work systems. A number of key resources were identified as reference points for A4BLUE use case owners and system developers to consider, and indicate where current gaps exist and might be improved by dissemination of A4BLUE results. The second section of the D1.1 Requirements Book (Annex H) lists the high level requirements resources as a reference guide for the project partners.

Work in the Beta phase of the project has been detailed in this D1.4 document version; this includes further development of User Level requirements capture (Section 4.1) and High Level requirements capture (Section 4.2). In addition, a Human Factors Best Practice guide section (Section 5) has been added to guide A4BLUE partners in their use case development, to ensure a human-centred / user-centred design approach.

The next steps for capturing user level requirements include a review of the survey design and much wider distribution of the bespoke survey. Consortium partners are asked to continue distribution of the survey globally, across populations beyond partner organisations. The survey was distributed more widely than the Alpha survey, and provided responses from individuals from a range of organisations and bringing their insight to the survey and its results. Due to the sample size a qualitative rather than in-depth statistical analysis was applied to the data. Ideally, it would be advantageous to achieve a sufficient number of responses from participants from all of the identified user groups to enable statistical analysis as this would enable group comparisons but this would also provide greater reliability. This is because the tendencies seen in current results summaries are likely to be biased because all of these, thus far, have been provided by partners and partners' contacts who are probably more technology-focused. It is therefore intended that the survey shall remain 'open' and available to allow a 'snowball' effect whereby the link is shared and new participants provide responses from a wider range of organisations and user groups. This may enable the collection of new data which would be analysed and reported in a public document that may be disseminated. Overall, results from both the Alpha and Beta phases supported the project's aims for developing adaptive and inclusive systems that comprise novel technologies, although these innovations were generally considered more "Desirable", than "Essential".

The next steps for high level requirements capture involved continued monitoring of legal and standards developments for technologies and topics related to the A4BLUE system designs, which remain focused on the design of new industrial systems with assimilated technologies. Most of the laws and standards presented in the Alpha phase remained unchanged but evidence has been presented from the Beta review of significant changes to legal frameworks, particularly for robot ethics and data protection, and to standards, particularly for collaborative and human-centred robotic applications. Direct implications for A4BLUE research and development need to be analysed and incorporated. As there is a fast-changing landscape in high level requirements for industrial systems and advanced technologies at the current time these developments will continue to be monitored and relevant standards will be reported in Deliverable D7.4 of task T7.3 about standardization.

7 REFERENCES

[1] EC (2010). *Guide to application of the Machinery Directive 2006/42/EC (2nd. Ed);* accessed 15/02/17 from: http://ec.europa.eu/DocsRoom/documents/9483/attachments/1/translations

[2] Harkness, J., Pennell, B & Schoua-Glusberg, A. (2004). Survey Questionnaire Translation and Assessment. In *Methods for Testing and Evaluating Survey Questionnaires* (Eds: Presser, S., Rothgeb, J.M., Couper, M.P., Lessler, J.L., Martin, E., Martin, J. & Singer. E.). New York: Wiley

[3] Perey, C., Engelke, T., & Reed, C. (2011). Current status of standards for augmented reality. In *Recent Trends of Mobile Collaborative Augmented Reality Systems* (pp. 21-38). Springer New York.

[4] Pilz (2017). Basics - harmonised standards, directives and laws in the EU; accessed 17/03/17 from: https://www.pilz.com/en-US/knowhow/law-standards-norms/standards

[5] Leva, M. C., Naghdali, F., & Alunni, C. C. (2015). Human Factors Engineering in system design: a roadmap for improvement. Procedia CIRP, 38, 94-99.

Annex A ALPHA: ORGANISATIONAL LEVEL REQUIREMENTS FOR FUTURE ASSEMBLY WORK SYSTEMS

"Assembly work systems in the future should have…"	Essential		Desirable		Unnecessary		No Answer		Overall agreement
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Percentage
Functions that are able to change their behaviour autonomously to accommodate new products and production processes.	24	48%	23	46%	3	6%	0	0%	94
The ability to easily reconfigure the workplace when introducing a new automated system or robotics (e.g. plug & produce capabilities).	33	66%	15	30%	2	4%	0	0%	96
The ability to optimise by themselves to reduce the need for human intervention and adjustment.	18	36%	27	54%	4	8%	1	2%	90
The ability to reconfigure themselves to increase efficiency and minimise effort and increase efficiency when changing production processes.	13	26%	33	66%	2	4%	2	4%	92
Continuous data collection for analysis of system performance and optimisation needs.	33	66%	17	34%	0	0%	0	0%	100
Self-adjusting capabilities to cope with changing needs of workforces and different worker capabilities	19	38%	28	56%	3	6%	0	0%	94
The ability to self-adjust to compensate for lower training and experience levels.	14	28%	25	50%	11	22%	0	0%	78
The ability to self-adjust to compensate for reduced technical capabilities (older computer programs).	12	24%	26	52%	10	20%	2	4%	76
On-the-job work instructions that guide the worker through assembly or support processes (i.e. inspection, routine maintenance) to reduce the need for organised off-the-job training and supervision.	33	66%	17	34%	1	2%	0	0%	98
Capabilities included in the automated system or robot that take advantage of the available workers expertise/ knowledge.	22	44%	22	44%	6	12%	0	0%	88
Continuous interaction all systems in the organisation for resource allocation.	24	48%	22	44%	4	8%	0	0%	92
Direct connection to organisational systems for post-production product service and support.	19	38%	24	48%	7	14%	0	0%	86
Constant recording of tool usage data to a central system to improve maintenance activities.	27	54%	22	44%	1	2%	0	0%	98
Constant recording of automation / robot usage data to a central system to manage maintenance activities.	24	48%	25	50%	1	2%	0	0%	98
Monitoring work station performance for future process improvement.	26	52%	22	44%	2	4%	0	0%	96
Constant logging of production waste data for the purposes of future planning.	18	36%	26	52%	6	12%	0	0%	88
Direct connection to internal control systems (e.g. Enterprise Resource Planning, Manufacturing execution systems, etc.) to adapt the assembly process.	29	58%	19	38%	2	4%	0	0%	96
The ability to evaluate optimal levels of automation for workers (i.e. from fully automated to fully manual through collaborative).	14	28%	33	66%	4	8%	0	0%	92
Abilities for determining optimal levels of automation to meet economic requirements.	16	32%	28	56%	5	10%	1	2%	88
Capabilities for evaluating workers' levels of satisfaction of and identify potential workplace improvements.	22	44%	24	48%	3	6%	1	2%	92

Annex B ALPHA: AUTOMATION AND ROBOTICS

"Assembly work systems in the future should have…"	Essential		Desirable		Unnecessary		No Answer		Overall agreement
	Frequency	Percentage	Frequency	Percentage	Percentage	Percentage	Frequency	Percentage	Percentage
Automation / robotics that are controllable by the operators working in the system	30	60%	18	36%	1	2%	1	2%	96
Automation / robotics that can only be adapted by management.	5	10%	14	28%	30	60%	1	2%	38
Automation / robotics that can change themselves safely to meet varying production demands.	20	40%	28	56%	2	4%	1	2%	94
Automation / robotics that can change safely on their own to meet different environmental conditions like varying light and noise levels.	17	34%	26	52%	5	10%	2	4%	86
Automation / robotics that can change safely by themselves to meet different physical capabilities of the involved operators, such as size differences.	27	54%	20	40%	2	4%	1	2%	94
Automation / robotics that can change safely on their own to meet different experience capabilities of the involved operators.	16	32%	28	56%	5	10%	1	2%	88
Automation / robotics that run at a constant rate or on a constant programme and do not change.	6	12%	13	26%	30	60%	1	2%	38
Automated / robotic functions that will adapt to suit each operator's preferred working methods.	6	12%	37	74%	6	12%	1	2%	86
Automation / robots that can adapt its speed to correspond with an operator's profile (i.e. expertise, skills, capabilities, preferences, trust level).	21	42%	24	48%	4	8%	1	2%	90
Robots that work collaboratively and safely with an operator on shared tasks in fenceless environments.	31	62%	17	34%	1	2%	1	2%	96
Safety mechanisms that make operators comfortable when collaborating with automation/robots during assembly.	42	84%	7	14%	0	0%	1	2%	98
Robots have safety capabilities that immediately stop the robot in the event of an accidental collision.	43	86%	4	8%	1	2%	2	4%	94
Robots have safety capabilities that move the robot away from the worker in the event of an accidental collision.	37	74%	10	20%	3	6%	1	2%	92
Safety capabilities that adapt the speed of the robot according to the distance or speed of the operator.	37	74%	10	20%	2	4%	1	2%	94
Functionalities to adapt the safety strategy based on the operators preferences and what is happening in the area surrounding the robot.	15	30%	25	50%	9	18%	1	2%	80
Safety capabilities that differentiate between people and other kinds of potential obstacles, and adapt the automation/robots behaviour to suit.	25	50%	23	46%	1	2%	1	2%	96
The ability to make operators aware of whether or not the safety mechanisms and devices are functioning effectively.	33	66%	16	32%	0	0%	1	2%	98
Robots should work safely alongside or near to an operator but on separate tasks.	14	28%	15	30%	20	40%	1	2%	58
Automation / robotics that can self-adapt its configuration to an operator's physical characteristics (i.e. height, arm length) to avoid potential ergonomic issues.	24	48%	24	48%	1	2%	1	2%	96
Robots that do not work with or in close proximity to humans.	8	16%	7	14%	35	70%	2	4%	29
Robots that notify management about the completion and the status of the task.	18	36%	23	46%	8	16%	1	2%	82

Annex C ALPHA: COMMUNICATION AND INTERACTION MECHANISMS

"Assembly work systems in the future should have…"	Essential		Desirable		Unnecessary		No Answer		Overall agreement
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Percentage
A workstation PC with an interactive computer system that allows the operator to interact and control the automation / robot / system.	28	56%	14	28%	8	16%	0	0%	84
Automation / robot / systems that can be controlled with a computer system on a mobile devise (e.g. tablet, smartphone).	15	30%	32	64%	3	6%	0	0%	94
Operators interacting non-verbally with automation / robot / system by using handheld controls, or an emergency stop button.	27	54%	18	36%	5	10%	1	2%	88
Automation / robot / systems that operators interact with using gestures.	8	16%	27	54%	15	30%	0	0%	70
Automation / robot / systems that operators interact with using pre-defined voice commands.	10	20%	30	60%	10	20%	0	0%	80
Automation / robot / systems that operators interact with using natural speaking (i.e. non-predefined commands).	4	8%	34	68%	12	24%	0	0%	76
Automation / robot / systems that operators can choose based on their preferences or capabilities to interact verbally and/or non-verbally with the automation / robot / system.	14	28%	23	46%	13	26%	0	0%	74
The automation / robot / system has feedback abilities to show that it has understood a command.	28	56%	18	36%	4	8%	0	0%	92
The automation / robot / system uses sound or voice message to provide feedback and notifications to workers.	14	28%	27	54%	9	18%	0	0%	82
The automation / robot / system has visual capabilities (e.g. computer systems, lights, projected messages, etc.) to display relevant feedback and notifications to operators.	20	40%	30	60%	0	0%	0	0%	100
The automation / robot / system has both visual and auditory capabilities to present relevant feedback and notifications.	15	30%	33	66%	2	4%	0	0%	96

Annex D ALPHA: SYSTEM FEEDBACK AND ASSISTANCE

"Assembly work systems in the future should have…"	Essential		Desirable		Unnecessary		No Answer		Overall agreement
	Frequency	Percentage	Frequency	Percentage	Percentage	Percentage	Frequency	Percentage	Percentage
System feedback that keeps the operator aware of their own work progress.	22	44%	24	48%	4	8%	0	0%	92
Process analysis and feedback that can be accessed when requested by operators, such as productivity and performance information.	21	42%	23	46%	6	12%	0	0%	88
Automatic and continuous analysis of work as it is completed and feedback mechanisms.	18	36%	27	54%	4	8%	1	2%	90
The ability to recognise an operators capability and provides personalised assistance.	12	24%	33	66%	5	10%	0	0%	90
An ability to detect when technical assistance is needed by an operator.	11	22%	36	72%	2	4%	1	2%	94
Functionality for providing the assistance that operators can request and/or select.	17	34%	30	60%	2	4%	1	2%	94
The ability to provide personalised assistance to meet the individual needs of an operator.	12	24%	31	62%	7	14%	0	0%	86
Ergonomic assessment capabilities so that it can provide postural guidance to operators.	20	40%	20	40%	10	20%	0	0%	80
Ergonomic assessment of physical capabilities of the operator to provide assistance.	20	40%	21	42%	8	16%	1	2%	82
Assistance and feedback that is designed to keep operators satisfied as they work.	16	32%	26	52%	8	16%	0	0%	84
All tools and equipment for assembly always available to operators.	25	50%	14	28%	11	22%	1	2%	76
Tools / equipment that are provided to operators at specific stages of assembly when they are needed.	28	56%	20	40%	1	2%	1	2%	96
Knowledge capture / capitalization systems for process improvement.	18	36%	30	60%	2	4%	0	0%	96
System optimisation proposal taken from feedback.	14	28%	31	62%	5	10%	0	0%	90
Augmented reality devices (e.g. google glasses) to provide remote assistance from qualified personnel to operators.	6	12%	38	76%	6	12%	1	2%	86
Automated systems that suggest how to manage emergency and/or unexpected situations.	21	42%	27	54%	2	4%	0	0%	96
An off-the-job system that uses virtual reality simulation to train operators to do tasks by reproducing it in a virtual world.	12	24%	27	54%	11	22%	0	0%	78

Annex E ALPHA: SYSTEM INFORMATION AND INSTRUCTIONS

"Assembly work systems in the future should have…"	Essential		Desirable		Unnecessary		No Answer		Overall Agreement
	Frequency	Percentage	Frequency	Percentage	Percentage	Percentage	Frequency	Percentage	Percentage
Virtual reality that provides off–the-job training to operators.	13	26%	28	56%	10	20%	0	0%	80
Augmented reality that provides information and instructions to operators while they are working.	18	36%	28	56%	5	10%	0	0%	90
The capability to display work procedures that show how to do tasks using multimedia capabilities (text, pictures, images, videos).	25	50%	26	52%	0	0%	0	0%	100
The ability to verify each step of the proposed procedure and display the information related to the next step.	20	40%	29	58%	1	2%	0	0%	98
Capabilities to allow operators to interrogate information / instructions further.	23	46%	27	54%	0	0%	0	0%	100
Mechanisms for operators to directly input their own recommendations for work instructions, information updates or working conditions.	16	32%	32	64%	4	8%	0	0%	92
Mechanisms for operators to directly input multimedia content (i.e. including photos, videos, and voice) into the process information and instructions.	12	24%	31	62%	7	14%	0	0%	86
Functions that track operators' activity and/or work performance and inform them of recommendations and remedial actions.	10	20%	30	60%	9	18%	1	2%	80
Information presented on demand using a wireless augmented reality device.	12	24%	29	58%	9	18%	0	0%	82
Capabilities that allow operators to exchange best practices/ problem solving solutions with other operators in the process instructions.	16	32%	29	58%	5	10%	0	0%	90

Annex F ALPHA: SYSTEM SECURITY AND DATA MANAGEMENT

"Assembly work systems in the future should have…"	Essential		Desirable		Unnecessary		No Answer		Overall Agreement
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Percentage
Only allow personnel who work on maintaining and overseeing the information technology systems to have access to an operator's data	15	30%	15	30%	19	38%	1	2%	60
Allow personnel who work on information technology systems AND managers to have access to the operator's data	10	20%	19	38%	20	40%	1	2%	58
Allow information technology personnel and managers to have access to system data (e.g. data on process, data on the systems performance)	29	58%	14	28%	7	14%	0	0%	86
Let anyone have access to an operator's data	1	2%	2	4%	47	94%	0	0%	6
Let anyone have access to system data	3	6%	5	10%	42	84%	0	0%	16
Destroy an operator's data 5 years after they have left their company of employment	13	26%	22	44%	14	28%	1	2%	70
Retain an operator's data indefinitely	1	2%	11	22%	38	76%	0	0%	24
Retain system data indefinitely	10	20%	15	30%	25	50%	0	0%	50
Only hold data for specific operators at specific workstations	1	2%	23	46%	26	52%	0	0%	48
Capture all data about operators' working activities	5	10%	19	38%	25	50%	1	2%	48
Only capture specific data about the operator (e.g. the height they set the workbench to)	11	22%	22	44%	15	30%	3	6%	65
Comprise IT security mechanisms that will prevent attacks from external sources	42	84%	7	14%	1	2%	0	0%	98

Annex G ANNEX G FULL LIST OF B-TYPE STANDARDS HARMONISED FOR THE MACHINERY DIRECTIVE 2006/42/EC

EN 349:1993+A1:2008	Safety of machinery - Minimum gaps to avoid crushing of parts of the human body
EN 547-1:1996+A1:2008	Safety of machinery - Human body measurements - Part 1: Principles for determining the dimensions required for openings for whole body access into machinery
EN 547-2:1996+A1:2008	Safety of machinery - Human body measurements - Part 2: Principles for determining the dimensions required for access openings
EN 547-3:1996+A1:2008	Safety of machinery - Human body measurements - Part 3: Anthropometric data
EN 574:1996+A1:2008	Safety of machinery - Two-hand control devices - Functional aspects - Principles for design
EN 614-1:2006+A1:2009	Safety of machinery - Ergonomic design principles - Part 1: Terminology and general principles
EN 614-2:2000+A1:2008	Safety of machinery - Ergonomic design principles - Part 2: Interactions between the design of machinery and work tasks
EN 842:1996+A1:2008	Safety of machinery - Visual danger signals - General requirements, design and testing
EN 894-1:1997+A1:2008	Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 1: General principles for human interactions with displays and control actuators
EN 894-2:1997+A1:2008	Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 2: Displays
EN 894-3:2000+A1:2008	Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 3: Control actuators
EN 894-4:2010	Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 4: Location and arrangement of displays and control actuators
EN 981:1996+A1:2008	Safety of machinery - System of auditory and visual danger and information signals
EN 1005-1:2001+A1:2008	Safety of machinery - Human physical performance - Part 1: Terms and definitions
EN 1005-2:2003+A1:2008	Safety of machinery - Human physical performance - Part 2: Manual handling of machinery and component parts of machinery
EN 1005-3:2002+A1:2008	Safety of machinery - Human physical performance - Part 3: Recommended force limits for machinery operation
EN 1005-4:2005+A1:2008	Safety of machinery - Human physical performance - Part 4: Evaluation of working postures and movements in relation to machinery
EN 1032:2003+A1:2008	Mechanical vibration - Testing of mobile machinery in order to determine the vibration emission value
EN 1037:1995+A1:2008	Safety of machinery - Prevention of unexpected start-up
EN 1093-1:2008	Safety of machinery - Evaluation of the emission of airborne hazardous substances - Part 1: Selection of test methods
EN 1093-2:2006+A1:2008	Safety of machinery - Evaluation of the emission of airborne hazardous substances - Part 2: Tracer gas method for the measurement of the emission rate of a given pollutant

EN 1093-3:2006+A1:2008	Safety of machinery - Evaluation of the emission of airborne hazardous substances - Part 3: Test bench method for the measurement of the emission rate of a given pollutant
EN 1093-4:1996+A1:2008	Safety of machinery - Evaluation of the emission of airborne hazardous substances - Part 4: Capture efficiency of an exhaust system - Tracer method
EN 1093-6:1998+A1:2008	Safety of machinery - Evaluation of the emission of airborne hazardous substances - Part 6: Separation efficiency by mass, unducted outlet
EN 1093-7:1998+A1:2008	Safety of machinery - Evaluation of the emission of airborne hazardous substances - Part 7: Separation efficiency by mass, ducted outlet
EN 1093-8:1998+A1:2008	Safety of machinery - Evaluation of the emission of airborne hazardous substances - Part 8: Pollutant concentration parameter, test bench method
EN 1093-9:1998+A1:2008	Safety of machinery - Evaluation of the emission of airborne hazardous substances - Part 9: Pollutant concentration parameter, room method
EN 1093-11:2001+A1:2008	Safety of machinery - Evaluation of the emission of airborne hazardous substances - Part 11: Decontamination index
EN 1127-1:2011	Explosive atmospheres - Explosion prevention and protection - Part 1: Basic concepts and methodology
EN 1127-2:2014	Explosive atmospheres - Explosion prevention and protection - Part 2: Basic concepts and methodology for mining
EN 1299:1997+A1:2008	Mechanical vibration and shock - Vibration isolation of machines - Information for the application of source isolation
EN 1837:1999+A1:2009	Safety of machinery - Integral lighting of machines
EN ISO 3741:2010	Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Precision methods for reverberation test rooms (ISO 3741:2010)
EN ISO 3743-1:2010	Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering methods for small movable sources in reverberant fields - Part 1: Comparison method for a hard-walled test room (ISO 3743-1:2010)
EN ISO 3743-2:2009	Acoustics - Determination of sound power levels of noise sources using sound pressure - Engineering methods for small, movable sources in reverberant fields - Part 2: Methods for special reverberation test rooms (ISO 3743-2:1994)
EN ISO 3744:2010	Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering methods for an essentially free field over a reflecting plane (ISO 3744:2010)
EN ISO 3745:2012	Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Precision methods for anechoic rooms and hemi-anechoic rooms (ISO 3745:2012)
EN ISO 3746:2010	Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Survey method using an enveloping measurement surface over a reflecting plane (ISO 3746:2010)
EN ISO 3747:2010	Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering/survey methods for use in situ in a reverberant environment (ISO 3747:2010)

EN ISO 4413:2010	Hydraulic fluid power - General rules and safety requirements for systems and their components (ISO 4413:2010)
EN ISO 4414:2010	Pneumatic fluid power - General rules and safety requirements for systems and their components (ISO 4414:2010)
EN ISO 4871:2009	Acoustics - Declaration and verification of noise emission values of machinery and equipment (ISO 4871:1996)
EN ISO 5136:2009	Acoustics - Determination of sound power radiated into a duct by fans and other air-moving devices - In-duct method (ISO 5136:2003)
EN ISO 7235:2009	Acoustics - Laboratory measurement procedures for ducted silencers and air-terminal units - Insertion loss, flow noise and total pressure loss (ISO 7235:2003)
EN ISO 7731:2008	Ergonomics - Danger signals for public and work areas - Auditory danger signals (ISO 7731:2003)
EN ISO 9614-1:2009	Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 1: Measurement at discrete points (ISO 9614-1:1993)
EN ISO 9614-3:2009	Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 3: Precision method for measurement by scanning (ISO 9614-3:2002)
EN ISO 11161:2007	Safety of machinery - Integrated manufacturing systems - Basic requirements (ISO 11161:2007)
EN ISO 11200:2014	Acoustics - Noise emitted by machinery and equipment - Guidelines for the use of basic standards for the determination of emission sound pressure levels at a work station and at other specified positions (ISO 11200:2014)
EN ISO 11201:2010	Acoustics - Noise emitted by machinery and equipment - Determination of emission sound pressure levels at a work station and at other specified positions in an essentially free field over a reflecting plane with negligible environmental corrections (ISO 11201:2010)
EN ISO 11202:2010	Acoustics - Noise emitted by machinery and equipment - Determination of emission sound pressure levels at a work station and at other specified positions applying approximate environmental corrections (ISO 11202:2010)
EN ISO 11203:2009	Acoustics - Noise emitted by machinery and equipment - Determination of emission sound pressure levels at a work station and at other specified positions from the sound power level (ISO 11203:1995)
EN ISO 11204:2010	Acoustics - Noise emitted by machinery and equipment - Determination of emission sound pressure levels at a work station and at other specified positions applying accurate environmental corrections (ISO 11204:2010)
EN ISO 11205:2009	Acoustics - Noise emitted by machinery and equipment - Engineering method for the determination of emission sound pressure levels in situ at the work station and at other specified positions using sound intensity (ISO 11205:2003)
EN ISO 11546-1:2009	Acoustics - Determination of sound insulation performances of enclosures - Part 1: Measurements under laboratory conditions (for declaration purposes) (ISO 11546-1:1995)

EN ISO 11546-2:2009	Acoustics - Determination of sound insulation performances of enclosures - Part 2: Measurements in situ (for acceptance and verification purposes) (ISO 11546-2:1995)
EN ISO 11554:2008	Optics and photonics - Lasers and laser-related equipment - Test methods for laser beam power, energy and temporal characteristics (ISO 11554:2006)
EN ISO 11688-1:2009	Acoustics - Recommended practice for the design of low-noise machinery and equipment - Part 1: Planning (ISO/TR 11688-1:1995)
EN ISO 11691:2009	Acoustics - Measurement of insertion loss of ducted silencers without flow - Laboratory survey method (ISO 11691:1995)
EN ISO 11957:2009	Acoustics - Determination of sound insulation performance of cabins - Laboratory and in situ measurements (ISO 11957:1996)
EN 12198-1:2000+A1:2008	Safety of machinery - Assessment and reduction of risks arising from radiation emitted by machinery - Part 1: General principles
EN 12198-2:2002+A1:2008	Safety of machinery - Assessment and reduction of risks arising from radiation emitted by machinery - Part 2: Radiation emission measurement procedure
EN 12198-3:2002+A1:2008	Safety of machinery - Assessment and reduction of risks arising from radiation emitted by machinery - Part 3: Reduction of radiation by attenuation or screening
EN 12254:2010	Screens for laser working places - Safety requirements and testing
EN 12786:2013	Safety of machinery - Requirements for the drafting of the vibration clauses of safety standards
EN 13490:2001+A1:2008	Mechanical vibration - Industrial trucks - Laboratory evaluation and specification of operator seat vibration
EN ISO 13732-1:2008	Ergonomics of the thermal environment - Methods for the assessment of human responses to contact with surfaces - Part 1: Hot surfaces (ISO 13732-1:2006)
EN ISO 13732-3:2008	Ergonomics of the thermal environment - Methods for the assessment of human responses to contact with surfaces - Part 3: Cold surfaces (ISO 13732-3:2005)
EN ISO 13753:2008	Mechanical vibration and shock - Hand-arm vibration - Method for measuring the vibration transmissibility of resilient materials when loaded by the hand-arm system (ISO 13753:1998)
EN ISO 13849-1:2015	Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design (ISO 13849-1:2015)
EN ISO 13849-2:2012	Safety of machinery - Safety-related parts of control systems - Part 2: Validation (ISO 13849-2:2012)
EN ISO 13850:2015	Safety of machinery - Emergency stop function - Principles for design (ISO 13850:2015)
EN ISO 13855:2010	Safety of machinery - Positioning of safeguards with respect to the approach speeds of parts of the human body (ISO 13855:2010)
EN ISO 13856-1:2013	Safety of machinery - Pressure-sensitive protective devices - Part 1: General principles for design and testing of pressure-sensitive mats and pressure-sensitive floors (ISO 13856-1:2013)
EN ISO 13856-2:2013	Safety of machinery - Pressure-sensitive protective devices - Part 2: General principles for design and testing of pressure-sensitive edges and pressure-sensitive bars (ISO 13856-2:2013)
EN ISO 13856-3:2013	Safety of machinery - Pressure-sensitive protective devices - Part 3: General principles for design and testing of pressure-sensitive bumpers, plates, wires and similar devices (ISO 13856-3:2013)

EN ISO 13857:2008	Safety of machinery - Safety distances to prevent hazard zones being reached by upper and lower limbs (ISO 13857:2008)
EN ISO 14119:2013	Safety of machinery - Interlocking devices associated with guards - Principles for design and selection (ISO 14119:2013)
EN ISO 14120:2015	Safety of machinery - Guards - General requirements for the design and construction of fixed and movable guards (ISO 14120:2015)
EN ISO 14122-1:2016	Safety of machinery - Permanent means of access to machinery - Part 1: Choice of fixed means and general requirements of access (ISO 14122-1:2016)
EN ISO 14122-2:2016	Safety of machinery - Permanent means of access to machinery - Part 2: Working platforms and walkways (ISO 14122-2:2016)
EN ISO 14122-3:2016	Safety of machinery - Permanent means of access to machinery - Part 3: Stairs, stepladders and guard-rails (ISO 14122-3:2016)
EN ISO 14122-4:2016	Safety of machinery - Permanent means of access to machinery - Part 4: Fixed ladders (ISO 14122-4:2016)
EN ISO 14123-1:2015	Safety of machinery - Reduction of risks to health resulting from hazardous substances emitted by machinery - Part 1: Principles and specifications for machinery manufacturers (ISO 14123-1:2015)
EN ISO 14123-2:2015	Safety of machinery - Reduction of risks to health resulting from hazardous substances emitted by machinery - Part 2: Methodology leading to verification procedures (ISO 14123-2:2015)
EN ISO 14159:2008	Safety of machinery - Hygiene requirements for the design of machinery (ISO 14159:2002)
EN ISO 14738:2008	Safety of machinery - Anthropometric requirements for the design of workstations at machinery (ISO 14738:2002, including Cor 1:2003 and Cor 2:2005)
EN ISO 15536-1:2008	Ergonomics - Computer manikins and body templates - Part 1: General requirements (ISO 15536-1:2005)
EN 15967:2011	Determination of maximum explosion pressure and the maximum rate of pressure rise of gases and vapours
EN 16590-1:2014	Tractors and machinery for agriculture and forestry - Safety-related parts of control systems - Part 1: General principles for design and development (ISO 25119-1:2010 modified)
EN 16590-2:2014	Tractors and machinery for agriculture and forestry - Safety-related parts of control systems - Part 2: Concept phase (ISO 25119-2:2010 modified)
EN ISO 19353:2016	Safety of machinery - Fire prevention and fire protection (ISO 19353:2015)
EN ISO 20643:2008	Mechanical vibration - Hand-held and hand-guided machinery - Principles for evaluation of vibration emission (ISO 20643:2005)
EN 30326-1:1994	Mechanical vibration - Laboratory method for evaluating vehicle seat vibration - Part 1: Basic requirements (ISO 10326-1:1992)

Annex H REQUIREMENTS BOOK: HIGH LEVEL REQUIREMENTS – RELEVANT STANDARDS FOR A4BLUE

European Machinery Directive Standards	
EN ISO 12100:2010	Safety of machinery - General principles for design -- Risk assessment and risk reduction
ISO 13849-1:2015	Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design
IEC 60204-1: 2016	Safety of machinery – Electrical equipment of machines – Part 1: General requirements
BS EN 614-2:2000+A1:2008	Safety of machinery - Ergonomic design principles. Interactions between the design of machinery and work tasks
EN ISO 11161:2007	Safety of machinery - Integrated manufacturing systems - Basic requirements
EN 842:1996 +A1:2008	Safety of machinery - Visual danger signals - General requirements, design and testing
EN 981:1996+A1:2008	Safety of machinery - System of auditory and visual danger and information signals
EN 894-1:1997+A1:2008	Safety of machinery - Ergonomics requirements for the design of displays and control actuators: General principles for human interactions with displays and control actuators
EN 894-2:1997+A1:2008	Safety of machinery - Ergonomics requirements for the design of displays and control actuators: Displays
EN 894-3:2000+A1:2008	Safety of machinery - Ergonomics requirements for the design of displays and control actuators: Control actuators
EN 894-4:2010	Safety of machinery - Ergonomics requirements for the design of displays and control actuators: Location and arrangement of displays and control actuators
EN 1005-2:2003+A1:2008	Safety of machinery - Human physical performance: Manual handling of machinery and component parts of machinery
EN 1005-3:2002+A1:2008	Safety of machinery - Human physical performance: Recommended force limits for machinery operation
EN 1005-4:2005+A1:2008	Safety of machinery - Human physical performance: Evaluation of working postures and movements in relation to machinery
EN ISO 14738:2008	Safety of machinery - Anthropometric requirements for the design of workstations at machinery
Automation and Robotics	
EN ISO 10218-1:2011	Robots and robotic devices — Safety requirements for industrial robots: Robot systems and integration
ISO/TS 15066:2016	Robots and robotic devices — Collaborative robots
BS 8611:2016	Robots and robotic devices. Guide to the ethical design and application of robots and robotic systems
Ergonomics and Human Factors	
EN ISO 9241-100:2010	Ergonomics of human-system interaction – Introduction to standards related to software ergonomics
EN ISO 9241-110:2006	Ergonomics of human-system interaction - Dialogue principles
EN ISO 9241-129:2010	Ergonomics of human-system interaction - Guidance on software individualization

EN ISO 9241-161:2008	Ergonomics of human-system interaction - Guidance on visual user-interface elements
EN ISO 9241-210:2010	Ergonomics of human-system interaction - Human-centred design for interactive systems
EN ISO 9241-303:2011	Ergonomics of human-system interaction - Requirements for electronic visual displays
EN ISO 9241-400:2007	Ergonomics of human-system interaction - Principles and requirements for physical input devices
EN ISO 9241-410:2008	Ergonomics of human-system interaction - Design criteria for physical input devices
EN ISO 9241-920:2009	Ergonomics of human-system interaction - Guidance on tactile and haptic interactions
EN ISO 6385:2016	Ergonomics principles in the design of work systems
EN 10075-1-2000	Ergonomic principles related to mental workload - General terms and definitions
EN ISO 14915-1:2002	Software ergonomics for multimedia user interfaces – Design principles and framework
Digital Systems	
EN 62264-1:2013	Enterprise-control system integration
EN 62541	OPC unified architecture
EN 62714-1:2014	Engineering data exchange format for use in industrial automation systems engineering - Automation markup language

Annex I BETA: ORGANISATIONAL LEVEL REQUIREMENTS FOR FUTURE ASSEMBLY WORK SYSTEMS

	Essential		Desirable		Unnecessary		No Answer		Overall Agreement
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Percentage
Autonomous assessment of requirements and adaptation to new products	8	36%	12	55%	2	9%	0	0%	91%
Autonomous assessment of requirements and alteration to new processes	8	36%	12	55%	2	9%	0	0%	91%
Reconfigurability for new automation or robotics, e.g. 'plug & produce' capabilities	11	50%	10	45%	0	0%	1	5%	95%
Continuous data collection for analysis of system performance and optimisation needs	16	73%	5	23%	1	5%	0	0%	95%
Functions that can adapt to suit new / different workforce requirements	8	35%	14	61%	1	4%	0	0%	96%
Systems that can detect and adjust to suit the requirements of different operators e.g. training and experience levels	9	41%	13	59%	0	0%	0	0%	100%
Self-adjusting to compensate for reduced technical capabilities, e.g. older technologies, functional	4	18%	14	64%	4	18%	0	0%	82%
On-the-job work instructions for workers	14	64%	5	23%	1	5%	2	9%	86%
Workstations that provide the same information to all workers	7	32%	7	32%	8	36%	0	0%	64%
Standardised off the job training for all workers	8	36%	9	41%	5	23%	0	0%	77%
Automated system or robot capabilities for utilising operators' expertise/ knowledge	10	43%	12	52%	1	4%	0	0%	95%
Continuous interaction of all systems in the organisation for resource allocation	11	50%	9	41%	2	9%	0	0%	91%
Automated systems and robots that operate in a standardardised way	11	50%	10	45%	1	5%	0	0%	95%
Direct connection to organisational systems for post-production product service and support	10	45%	11	50%	1	5%	0	0%	95%
Constant recording of tool usage data to a central system to monitor maintenance activities	13	59%	8	36%	0	0%	1	5%	95%
Constant recording of automation / robot usage data to a central system to manage maintenance activities	13	59%	9	41%	0	0%	0	0%	100%
Monitoring work station performance for future process improvement	16	73%	5	23%	1	5%	0	0%	95%
Constant logging of production waste data for the purposes of future planning	15	68%	4	18%	2	9%	1	5%	86%
Direct connection to internal control systems (e.g. Enterprise Resource Planning) to adapt the assembly process	10	45%	11	50%	0	0%	1	5%	95%
Ability to assess and adapt to optimal levels of automation for individual workers	5	23%	15	68%	2	9%	0	0%	91%
Abilities for evaluating and selecting optimal levels of automation to meet economic requirements	11	50%	8	36%	3	14%	0	0%	86%
Capabilities for evaluating workers' levels of satisfaction	5	23%	14	64%	3	14%	0	0%	86%

Abilities for determining optimal levels of automation to maintain operator satisfaction	6	27%	14	64%	2	9%	0	0%	91%
Capabilities that adapt to workers' levels of satisfaction	6	27%	12	55%	3	14%	1	5%	82%
Automatic responses to answer manual requests from operators	10	45%	7	32%	5	23%	0	0%	77%

Annex J BETA: AUTOMATION AND ROBOTICS

	Essential		Desirable		Unnecessary		No Answer		Overall Agreement
	Frequency	Percentage	Frequency	Percentage	Frequency		Frequency	Percentage	Frequency
Manually controllable functions that can be used by operators	9	41%	10	45%	2	9%	1	5%	86%
Autonomous adaptation to varying production demands	10	45%	10	45%	0	0%	2	9%	91%
Autonomous adaptation to varying environmental conditions, e.g. light and noise levels	10	43%	8	35%	3	13%	2	9%	78%
Autonomous detection and adaptation of functions in response to workers characteristics, e.g. skill, age, experience	8	36%	10	45%	2	9%	2	9%	82%
Standardised system programs / consistent behaviour, e.g. speed, procedure	9	41%	5	23%	6	27%	2	9%	64%
Personalisable functions to satisfy individual operators' preferences, e.g. working methods, speed etc.	5	23%	11	50%	5	23%	1	5%	73%
Autonomous adaptation of programs to correspond with operators' capabilities and preferences	6	27%	9	41%	6	27%	1	5%	68%
In-built functions to enable collaborative work (on shared tasks) with operators without physical guarding	10	45%	11	50%	0	0%	1	5%	95%
Mechanisms for maintaining operators' awareness of process status	6	27%	14	64%	0	0%	2	9%	91%
Mechanisms for making operators aware of safety status	13	59%	7	32%	0	0%	2	9%	91%
Collision avoidance detection and stop functions	17	77%	4	18%	0	0%	1	5%	95%
Autonomous detection and adjustment of speed to suit the distances and / or speeds of operators	10	45%	9	41%	1	5%	2	9%	86%
Ability to distinguish people from other system features and adapt behaviour	10	45%	11	50%	0	0%	1	5%	95%
Mechanisms that alert operators of safety status and functioning	16	73%	5	23%	0	0%	1	5%	95%
In-built functions to enable co-existing work (on separate tasks but near to an operator) without physical guarding	8	36%	10	45%	2	9%	2	9%	82%
Adaptability of position and configuration to suit operators' physical characteristics, e.g. height, reach	5	23%	15	68%	1	5%	1	5%	91%
Automatic feedback to management on process status / task completion	8	36%	9	41%	3	14%	2	9%	77%
Functions for teaching workers how to perform tasks	7	32%	9	41%	3	14%	3	14%	73%
Automatic updates on information concerning process / production	14	64%	5	23%	1	5%	2	9%	86%
Automatic detection of workforce / operator profiles	4	18%	12	55%	4	18%	2	9%	73%
Automatic feedback to operators of updates to process / production information	13	59%	6	27%	1	5%	2	9%	86%
Mechanisms for providing information when requested by operators	10	45%	10	45%	1	5%	1	5%	91%

Annex K BETA: COMMUNICATION AND INTERACTION MECHANISMS

	Essential		Desirable		Unnecessary		No Answer		Overall Agreement
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Percentage
Interactive systems that allow operators to control functions and automation / robots	10	45%	9	41%	0	0%	3	14%	86%
Systems that can be controlled using handheld mobile devices, e.g. tablet, smartphone	7	32%	12	55%	1	5%	2	9%	86%
Fixed / static controls, e.g. mounted console / tablet	5	23%	10	45%	4	18%	3	14%	68%
Wearable control devices	4	18%	13	59%	3	14%	2	9%	77%
Augmented reality devices that provide controls, e.g. 'Google glasses'	5	23%	9	41%	4	18%	4	18%	64%
Gesture control interaction systems	6	27%	9	41%	5	23%	2	9%	68%
Defined voice command interaction systems (with limited standardised vocabulary and command options)	4	18%	7	32%	8	36%	3	14%	50%
Non-defined voice command interaction systems (using natural speech with unlimited vocabulary)	3	14%	9	41%	8	36%	2	9%	55%
Adaptable systems where workers can choose the mode of interaction they use	4	18%	15	68%	1	5%	2	9%	86%
Feedback mechanisms that show if the system has understood a command	14	64%	6	27%	0	0%	2	9%	91%
Speech / voice messages to operators for providing auditory notifications / work instructions	3	14%	14	64%	2	9%	3	14%	77%
Visual display of messages to operators providing text or graphic notifications / work instructions	13	59%	7	32%	0	0%	2	9%	91%
Traditional computer based format for providing work instructions	6	27%	9	41%	4	18%	3	14%	68%
Mechanisms for operators to provide feedback on process / task status	12	55%	7	32%	1	5%	2	9%	86%
Mechanisms for operators to report personal circumstances and concerns	10	45%	4	18%	6	27%	2	9%	64%
Interaction capabilities that enable real-time query-response communications	12	55%	7	32%	1	5%	2	9%	86%
Combined visual and auditory messages for feedback and notifications	5	23%	12	55%	2	9%	3	14%	77%
Mobile devices for communications and receiving notifications	5	23%	13	59%	2	9%	2	9%	82%
Wearable devices for communications and receiving notifications	3	14%	11	50%	5	23%	3	14%	64%
Personalisable communication devices for sending / receiving individual updates and information	4	18%	9	41%	6	27%	3	14%	59%
Mechanisms for operators to share practices/ problem solving solutions informally	5	23%	13	59%	2	9%	2	9%	82%
Interactive systems that enable operators to interrogate information / instructions more deeply when needed	11	50%	8	36%	0	0%	3	14%	86%
Interactivity that enables operators to verify each completed task step / retrieve information on the next step	9	41%	10	45%	0	0%	3	14%	86%

Annex L BETA: WORK SYSTEM FEEDBACK, TRAINING, AND ASSISTANCE

	Essential		Desirable		Unnecessary		No Answer		Overall Agreement
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Percentage
Feedback from the work system that keeps the operator aware of their own work progress	9	41%	10	45%	1	5%	2	9%	86%
Feedback from the work system to keep operators aware of overall system performance	6	27%	11	50%	3	14%	2	9%	77%
Continuous automatic feedback from the system	7	32%	9	41%	3	14%	3	14%	73%
Provision of specific feedback when requested by operators	10	45%	8	36%	1	5%	3	14%	82%
Personalised assistance provided by the system to suit operators' individual capabilities	5	23%	12	55%	3	14%	2	9%	77%
Standardised assistance and guidance provided by the system to suit all operators	11	50%	4	18%	4	18%	3	14%	68%
Automatic detection and provision of assistance	5	23%	12	55%	2	9%	3	14%	77%
Assistance provided when requested by operators	15	68%	5	23%	0	0%	2	9%	91%
Virtual reality simulation training methods to develop operator competencies 'off–the-job'	5	23%	12	55%	3	14%	2	9%	77%
Augmented reality training methods that provides off- and on–the-job training for operators	6	27%	12	55%	1	5%	3	14%	82%
Provision of ergonomic training from the work system	9	41%	10	45%	1	5%	2	9%	86%
Personalised ergonomic assessment from the system to identify individual operator needs	13	59%	6	27%	1	5%	2	9%	86%
Generic ergonomic / postural guidance from the system	9	41%	9	41%	2	9%	2	9%	82%
Automatic provision of assistance when system detects ergonomic needs of an operator	4	18%	13	59%	2	9%	3	14%	77%
Automatic assessment of operators' levels of satisfaction	2	9%	13	59%	3	14%	4	18%	68%
Assistance / feedback from the system to keep operators satisfied as they work	4	18%	10	45%	5	23%	3	14%	64%
Constant availability of tools and equipment	11	48%	8	35%	1	4%	3	13%	83%
Tools / equipment provided by the system in response to specific requests from operators	6	27%	12	55%	1	5%	3	14%	82%
Provision of tools / equipment at specific stages of assembly via system monitoring of progress	8	36%	11	50%	0	0%	3	14%	86%
Automatic provision of tools / equipment when system detects need	9	41%	9	41%	1	5%	3	14%	82%
Mechanisms for operators to directly input knowledge and process improvement ideas	10	45%	10	45%	0	0%	2	9%	91%
Augmented reality devices to provide remote assistance from other personnel / more experienced operators	7	32%	13	59%	0	0%	2	9%	91%
Automatic detection of / guidance for emergency and/or unexpected situations	12	55%	7	32%	1	5%	2	9%	86%
Augmented reality that provides information and instructions to workers while they are working	8	36%	11	50%	0	0%	3	14%	86%

Annex M BETA: SYSTEM SECURITY AND DATA MANAGEMENT

	Essential		Desirable		Unnecessary		No Answer		Overall Agreement
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Percentage
Systems automatically capture system performance data	15	68%	4	18%	0	0%	3	14%	86%
Systems automatically capture individual operator performance data	7	32%	6	27%	6	27%	3	14%	59%
Systems automatically analyse data	15	68%	4	18%	0	0%	3	14%	86%
Systems automatically report performance data to managers	8	35%	11	48%	1	4%	3	13%	83%
Access to operators' personal data is only available to personnel who work on the maintenance of information technology systems	8	36%	4	18%	7	32%	3	14%	55%
Managers to have access to operators' personal data	2	9%	6	27%	10	45%	4	18%	36%
System data (on processes, performance, etc.) can be accessed by information technology maintenance personnel	9	41%	5	23%	4	18%	4	18%	64%
Managers to have access to system data (on process, performance, etc.)	9	41%	6	27%	4	18%	3	14%	68%
Operator data is retained for predefined limited period of time	5	22%	10	43%	5	22%	3	13%	65%
System data is retained for a predefined limited period of time	7	32%	9	41%	2	9%	4	18%	73%
Data is only be captured / retained for specific operators / specific workstations	4	18%	7	32%	7	32%	4	18%	50%
Operator data for all workers is kept on the 'cloud' so that individual profiles can be downloaded when they log on to a workstation	4	18%	9	41%	5	23%	4	18%	59%
Operator profile data is automatically updated when systems detect changes, e.g. in ability, speed, etc.	4	18%	6	27%	8	36%	4	18%	45%
Data is captured equally across all workstations and roles	11	50%	5	23%	2	9%	4	18%	73%
Operator data includes information about all activities at work	5	23%	6	27%	7	32%	4	18%	50%
Operator data only includes assembly task performance	5	23%	4	18%	9	41%	4	18%	41%
Operator data only includes ergonomic information, e.g. the height they set the workbench	3	14%	8	36%	7	32%	4	18%	50%
Security mechanisms are required to prevent attacks from external sources	13	59%	4	18%	0	0%	5	23%	77%
Identity cards are needed for operators to log on before using a workstation	10	45%	6	27%	2	9%	4	18%	73%
All workstations are password protected	15	68%	4	18%	0	0%	3	14%	86%
Only selected workstations are password protected	6	27%	0	0%	11	50%	5	23%	27%