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Part 810:
Robotic, intelligent and autonomous systems

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 4, *Ergonomics of human-system interaction*.

A list of all parts in the ISO 9241 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Product development of systems with robot, intelligent and autonomous characteristics is rapidly progressing. Given the human-system issues of such systems, timely guidance covering these issues is necessary to help all sectors of industry to design, field and operate first-time quality robotic, intelligent, autonomous (RIA) systems, and build appropriate trust in products and services that use these systems.

There is an urgent need for a Technical Report from ISO explaining the existing, emerging and potential human-system issues and consequences for use and users associated with systems that have robot, intelligent and autonomous characteristics. This document explains the existing, emerging and potential human-system issues and consequences for use and users associated with systems that have RIA characteristics. It identifies the potential risks and priorities for standardization to address these issues. Solutions will be the subject of future standards.

This document reviews the ergonomics for a range of RIA systems. It describes the human-system issues that should be considered in the application of these technologies and identification of priorities for future standardization work. The purpose of this study is to identify and explore the ramifications of a categories of issues involving RIA systems that suggest a need to reset the boundaries of what is called ergonomics. The conclusion is that to make an ergonomic RIA system, the practice of ergonomics will need to do more, working together with new disciplines, and can require new tools, methods and approaches to support the design and integration of these types of systems into working environments and organizations. Ergonomics will also need to identify relevant research from a wide variety of scientific disciplines, as well as conducting our own research to ensure we have a robust evidence base to guide the development of these systems.

The paradigm behind human-systems interaction standards so far has been that of tool use. The ISO 9241 series is for interactive tools and the physical environment within which they are used. RIA systems necessitate a new paradigm. Agents developed using these technologies will be more connected, complex, probabilistic and non-deterministic, social, and augment human capabilities well beyond merely replacing physical work. Interaction with these agents can become a relationship, their interface a personality, and users and agents can form complex human-machine teams, working together towards a shared goal.

The evolution of RIA systems will significantly alter the nature of tasks users perform. The design of work will likewise be altered. Applications of RIA systems represent a significantly more complete and impactful replacement of human activity than has been seen with any other form of technological labour-saving device. For example, when working with another person on a common task, how do you diagnose a failure state in your interactions? How are you to interpret the off-nominal behaviour of a team member? How are you to interpret and predict the behaviour of other people who are operating within the same environment as you are but are otherwise not directly coordinating activity? What is the safe state you can fall back on in the event of a failure in your interaction with another person? Now, replace that person or team member with an RIA system. The changes in the nature of tasks and the design of work to accommodate the complex, social human-machine interaction of an RIA system is fundamental for ergonomics, but will require that the ergonomics community adapt its best practices and expand into areas of psychology and sociology that few ergonomists deal with on a regular basis.

The focus of this document is breadth not depth, and issues not answers. The emphasis is on describing general issues and the consequences of not addressing them, even though not all will/can be relevant to all types or applications of RIA systems covered by this document. But be sure that this is the case for your application, and that you take account of the categories of issue and context that do apply.

Ergonomics of human-system interaction —

Part 810:
Robotic, intelligent and autonomous systems

1 Scope

This document addresses:

— physically embodied RIA systems, such as robots and autonomous vehicles with which users will physically interact;

— systems embedded within the physical environment with which users do not consciously interact, but which collect data and/or modify the environment within which people live or work such as smart building and, mood-detection;

— intelligent software tools and agents with which users actively interact through some form of user interface;

— intelligent software agents which act without active user input to modify or tailor the systems to the user's behaviour, task or some other purpose, including providing context specific content/information, tailoring adverts to a user based on information about them, user interfaces that adapt to the cognitive or physiological state, "ambient intelligence";

— the effect on users resulting from the combined interaction of several RIA systems such as conflicting behaviours between the RIA systems under the same circumstances;

— the complex system-of-systems and sociotechnical impacts of the use of RIA systems, particularly on society and government.

This document is not an exploration of the philosophical, ethical or political issues surrounding robotics, artificial intelligence, machine learning, and intelligent machines or environments. For matters of ethics and political issues, see standards such as BS 8611 and IEC P7000. However, this document does identify where and why ethical issues need to be taken into account for a wide range of systems and contexts, and as such it provides information relevant to the broader debate regarding RIA systems.

This document has a broader focus than much of the early work on autonomy that relates to the automation of control tasks and mechanization of repetitive physical or cognitive tasks, and centres on levels of automation.

Although this document addresses a wide range of technology applications, and sector and stakeholder views on the issues, the treatment of each can be incomplete due to the diverse and increasingly varied applications of RIA systems.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Symbols and abbreviated terms

AI	artificial intelligence
CRM	crew resource management
DM	decision making
GPS	global positioning system
HCD	human-centred design
HCI	human-computer interaction
HCQ	human-centred quality (see ISO 9241-220)
HF	human factors
IA	intelligent agent
ICT	information and communications technology
IVR	interactive voice response
ML	machine learning
OODA	observe–orient–decide–act
RIA	robotic, intelligent, autonomous
RPA	robotic process automation
UxV	unmanned (where x = space, air, ground, surface, sub-surface) vehicle
UI	user interface
UX	user experience

5 Report contents and structure

The target audience for this document is decision-makers, designers and engineers who would benefit from the consideration of human-systems issues of RIA systems. Futurists, researchers, technology developers, regulators and legislators can also find this document useful.

The target audience for this document is the standards development community and ergonomists involved in developing, acquiring and/or commissioning RIA systems.

This document is based on an analysis that projects forwards from current applications of technology to more connected, complex, probabilistic and non-deterministic, social systems/entities/agents, and human augmentation. Social in this context also includes physical interaction. Applications considered include robots, intelligent systems and environments such as smart buildings that control or otherwise influence an environment, and autonomous agents/systems. The analysis considers views and concerns of: RIA system users and stakeholders from various industry sectors regarding the impact on future job roles, human tasks and organizational structures, safety, system trust, rights and culture. The limits for ergonomics are considered together with an initial identification of potential areas of change. A broad range of published sources and expertise was drawn on during the creation of this document. It includes the futurology literature, regulatory work, input from astute observers and reports of current and planned products. Extensive discussion and analysis by the project team is also included.

— Clause 6 discusses relevant concepts in AI and ergonomics.

— Clause 7 describes the groups of identified issues.

— Clause 8 describes the hazards and possible harm that can result if Ergonomics is not applied.

— Clause 9 describing how various existing ergonomics standards address the issues.

— Clause 10 describes the changes in ergonomics standards required to better address RIA systems technology.

Annexes A to E are written for:

— the ergonomics community — to give their input to RIA system projects/discussions face validity, provide food for thought regarding how ergonomics can be applied/should evolve/needs to be supported, gives a framework for issues to raise if involved with such projects;

— those developing, acquiring, commissioning or approving RIA systems — providing a set of considerations and potential issues to think about for those in any executive, project, design or legal and regulatory role;

— developers and users of standards who need to understand how the ergonomics aspects of RIA systems affect their activities — alerting those who have not so far included human or ergonomic requirements in relation to RIA systems in their domains to new or emergent human-system issues or needs.

Annex A elaborates the human-system issues within each category. Annex B presents examples of RIA systems, illustrating the issues, hazards, and ergonomics considerations. Annex C provides a two-stage review of the areas in which ergonomics needs to develop to address these issues. Annex D contains a more detailed description of the analysis and notes on the necessary extensions to ergonomics and standards. Annex E describes the analysis on which this document is based.

6 Concepts

6.1 General

There are many technologies used to implement RIA systems, various combinations of which are employed across a huge range of applications with which humans will interact. This has led to a general lack of agreement and precision in definitions and terminology, including those within standards where RIA system technologies and applications are defined in various ways according to specific requirements of the given context. As it is not possible to fully predict the different ways in which such technologies will be developed and applied in the future, this document does not refer to existing definitions from other standards. Instead, this document uses generic and commonly used terms because, although these can still invoke different individual interpretations and opinions, they are more generally and widely understood.

This document uses the most common generic terms in the title (robotic, intelligent, autonomous) with the understanding that they can trigger a range of associations and differences of opinion. These are not conceptually independent. Furthermore, this document focusses on their use by humans as collective descriptions for characteristics of types of intelligent agent. These agents are often qualified as to type or context of use (for example, autonomous car, intelligent building, care robot).

6.2 IT concepts

6.2.1 Intelligent agent

An intelligent agent is an entity which observes through sensors and acts on an environment using actuators. It directs its activity towards achieving goals. Intelligent agents can learn or use knowledge to achieve these goals. They can be very simple or very complex.

Intelligent agents are often software entities that carry out some set of operations on behalf of a user or another program with some degree of independence or autonomy, and in so doing, employ some knowledge or representation of the user's goals or desires. For example, autonomous programs used for operator assistance or data mining (sometimes referred to as bots) are also called "intelligent agents".

6.2.2 Autonomous agent

An autonomous agent is an intelligent agent operating on an owner's behalf with a high degree of independence.

Such an agent is a system situated in, and part of, a technical or natural environment, that senses any or some status of that environment, and acts on it in pursuit of its own agenda. The agenda evolves from drives (or programmed goals). The agent acts to change part of the environment or of its status and influences what it sensed.

Non-biological examples include intelligent agents, autonomous robots and various software agents, including artificial life agents, and many computer viruses. Biological examples are not yet defined (apart from living organisms).

NOTE Autonomy is a system property; it does not necessarily imply artificial intelligence.

The term machine learning is often used in conjunction with intelligent agents and some definitions of an autonomous system include the ability to learn as a characteristic of such systems.

6.2.3 Machine learning

Machine learning (ML) is a field of artificial intelligence that uses statistical techniques to give computer systems the ability to "learn" (e.g. progressively improve performance on a specific task) from data, without being explicitly programmed.

6.2.4 Autonomous robot

An autonomous robot is a robot that performs behaviours or tasks with a high degree of independence. This feature is particularly desirable in fields such as spaceflight, household maintenance (such as cleaning), waste water treatment and delivering goods and services.

Some modern factory robots are autonomous within the strict confines of their direct environment. It may not be that every degree of freedom exists in their surrounding environment, but the factory robot's workplace is challenging and can often contain chaotic, unpredicted variables. The exact orientation and position of the next object of work and (in the more advanced factories) even the type of object and the required task is determined. This can vary unpredictably (at least from the robot's point of view).

One important area of robotics research is to enable the robot to cope with its environment whether this is on land, underwater, in the air, underground or in space.

NOTE An autonomous robot is an embodied intelligent agent.

A fully autonomous robot can:

— gain information about the environment;

— work for an extended period without human intervention;

— move either all or part of itself throughout its operating environment without human assistance;

— avoid situations that are harmful to people, property or itself unless those are part of its design specifications;

— an autonomous robot can also learn or gain new knowledge like adjusting for new methods of accomplishing its tasks or adapting to changing surroundings;

— like other machines, autonomous robots can require regular maintenance.

6.2.5 ISO robot

The use of the term “robot” in this document is intended to include devices covered by the definition provided in ISO 8373:2012, 2.6.

The broader use of this term in this document is intended to accommodate variations and overlaps in the conceptualization, design and application of robots/robotics, and to avoid more specific definitions (like the definition in ISO 8373) that can pertain only to individual models and applications of robot as capabilities continue to evolve.

6.3 Ergonomics concepts

6.3.1 Ergonomics concern for RIA systems

There is a diverse range of interacting influences to be considered in the design of work involving RIA systems. Adaptation/evolution of ergonomics and its standards are required to better address RIA system issues/problems. Some of these topics are presently not within the scope of ergonomics to address. Ergonomics has traditionally concerned itself with physical and cognitive acts in a physical world. It is now addressing interactive systems and the digital world that extends to information, both about the physical world and of itself including science, business information systems, entertainment and knowledge. With RIA technology, ergonomics can also need to consider social ergonomics in order to assess and assist user experience, accessibility, usability and avoidance of harm. Ergonomics can need to extend its scope to take account of the effect of social interaction with and through RIA systems including social media, human-machine teaming, and adaptive interfaces and environments. Likewise, ergonomics can need to explore the impact to non-users of RIA systems who are in the environment in which the RIA systems are operating but are not using the RIA systems. Ergonomics can also need to take account of legal, regulatory and governance requirements that are being set by other parties, largely or even completely without ergonomics input.

6.3.2 Design approaches for RIA systems

There is a range of design approaches that can be taken when designing the relationship between an RIA system and its users, both human and other RIA systems. These are described in Table 1. They have ergonomic, sociotechnical, ethical and possibly political implications. Ergonomics applied to RIA systems should consider the most suitable paradigm for an application and the effect on individuals and society.

Table 1 — Design approaches for RIA systems

Design approach	Description	Benefit/Caution
Augmentation	The system improves human performance (including decision aids, exoskeletons, physical and/or cognitive prosthetics).	Extends human performance and capability. Possible health and ethical issues regarding elective use of augmentation for some advantage either to individual or society.

Table 1 *(continued)*

Design approach	Description	Benefit/Caution
Replacement	The system replaces human functions and/or entire human jobs.	Good for disliked, hazardous, repetitive or mundane jobs and those where there are skill shortages in the labour pool and where productivity can be improved. Unthinking application of replacement for specious purposes (such as unsupported safety and financial benefits).
Remoting	Allows the user to act on the physical environment at distance.	Good for safety, enabling a single user to control or interact with multiple physically distributed systems. Also, for use at distance for other reasons than safety, such as time to gain access, scale, extended observation or cost (such as extra-terrestrial, microscopic and marine exploration). Potential ethical issues of separation of operator from consequences of action and actions occurring under different legal regimes.
Teaming	The human and machine work together for a common goal (need be social).	Beneficial goals are facilitated (such as emotional components of user experience, efficiency and safety).
Symbiosis	The human and the system are closely linked working together for mutual benefit such as open, online courses and games in which the users get excitement and knowledge, and the system gets training.	Mutual benefit provided that both parties are aware of the agreements that they are entering into and do not abuse the relationship.
Parasitic	The human is a source of data collected by the system, but with little or no benefit to the human.	Not necessarily harmful but human not necessarily aware of RIA system action. This can be an issue that certain financial, political and organizational preconditions can foster, and that ergonomics should warn against. For example, designing an informed consent procedure.
Influence	Intelligent systems influencing human behaviour such as social media chatbots.	Behaviour can be influenced for the better. For example, safer. Regulation and licencing of pervasive, intelligent, automated propaganda and advertising.
Unknown alternatives	As yet undefined paradigms relating to organizational, social/cultural, societal relationships with RIA systems.	This is where the ergonomists need to cooperate with the experts on developmental psychology, sociology, business studies, law, etc.
Benevolent governance	Humans/humanity passing governance to AI.	For safety, collective benefit, reduction of hazards beyond human action. Agency is benevolent, having the best interests of society as the guiding principle. Agency provides governance: monitoring, evaluating, and directing plans and policies. Authority and safeguarding.

6.3.3 Perceived autonomy

From a human-centred point of view, apparently autonomous behaviour is a human-system issue and should be addressed in design. Indeed, from the human-system interaction perspective the degree to which system behaviour is perceived as autonomous can be a more important measure than the technical degree of autonomy of a system.

Since 2015, the terms "autonomous" and "autonomous system" have been widely used in marketing and journalism as synonyms for "automatic", "automation", and to describe systems with perceived autonomous behaviour. This usage is so widespread that it is not possible to assume any more precise meaning even in technical literature or regulation. As a result, behaviour that is perceived by a user as "autonomous" is a more common phenomenon than an autonomous agent.

6.3.4 Control loop

The control loop consists of the fundamental control functions, supporting information, affecters and effectors necessary for making adjustments in a process. A user, autonomous agent or other component of a system is said to be in the loop if that user, autonomous agent or component is in the process flow for making adjustments to the process. With the advent of RIA system agents, finer descriptions of where in the loop the user is located are emerging. For example, users who are in the loop during the execution of an automatic or autonomous process have interactions of a predominantly supervisory nature. An example of a less prevalent change in the use of in the loop is users who are before the loop. Such users have interactions prior to execution of an automatic or autonomous process but have no responsibilities for monitoring or making adjustments during the execution of the process. For a discussion of the decision/action cycle (OODA loop), see 10.3.

7 Categories of human-RIA system issues

7.1 General

The identified human-RIA system issues (problems) fall into six categories. These are summarized in Figure 1 and described in 7.2 to 7.7. Examples of ISO standards that can be related to these categories can be found in Clause 9.

This clause presents data for analysis, not conclusions. It describes human-system issues that are specific or particularly relevant to RIA systems rather than those that are common to non-RIA systems.

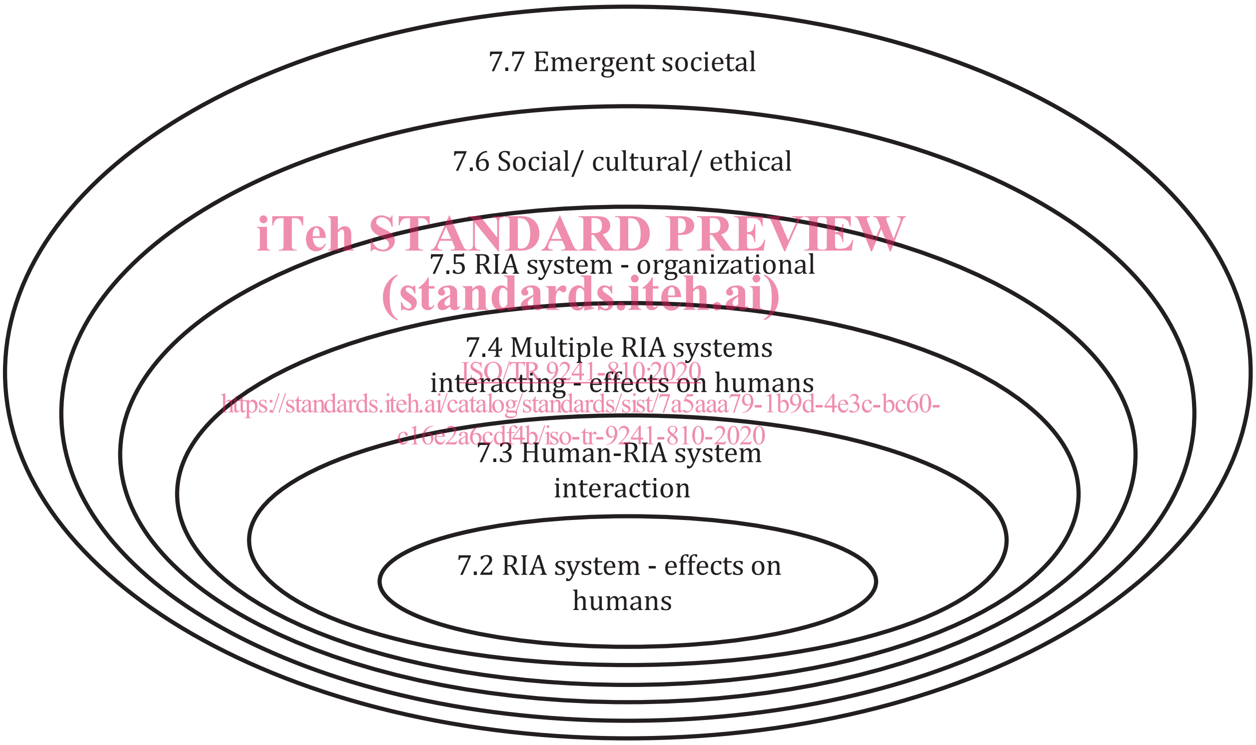

Figure 1 — The six categories of RIA system issues identified

7.2 RIA system — effects on a human

This first category represents the impact that the characteristics of an RIA system have on individual humans who are in the environment where it is operating. This includes physical, cognitive, affective, behavioural and motivational responses.

It should be stressed that the issues in this category are not limited to those experienced by users (those interacting with the RIA system or for whom its effects are intended). Unless an RIA system is totally unobtrusive, it impacts non-users as well, who have no vested interest in what it is doing. With respect to the non-users, an obtrusive RIA system in their environment can alter the way they perceive their environment, prompt an emotional response and alter their behaviour. For example, the mere presence of an RIA system can be perceived as a distraction or as an invasion of privacy or personal space. Therefore, one cannot expect the same effects to occur for users and non-users.

See A.2 for more examples of issues associated with how RIA system designed characteristics affect humans.

7.3 Human-RIA system interaction

Unless an RIA system is completely autonomous, humans interact with it directly at some level or to some degree. The humans in this category constitute users of the RIA system. This category is where most ergonomics resides today. It addresses the nature of tasks and the design of work to ensure that users are able to accomplish their intended tasks. The issues in the category specifically cover the consequences and impact of the design of the user interface on user (i.e. individual or team) interactions with the RIA system.

See A.3 for more examples of issues associated with human-RIA system interaction.

7.4 Multiple RIA systems interacting — effects on humans

One can anticipate that the time will come when multiple RIA systems operate within the same environment, coordinating activity and interacting without human intervention. Interactions can be obvious to the user, in the case of a physically embodied RIA system, or hidden, as can be the case with software agents, where the user only perceives a single system rather than its constituent elements. Where RIA systems from different suppliers or organizations interact, compatibility and communication issues between one RIA system and another are foreseeable, as well as with the humans present in environments where multiple RIA systems are operating. It is difficult to predict what emergent behaviours will result and their effect on users.

See A.4 for more examples of issues associated with the effects on humans of interacting RIA systems.

7.5 RIA system — organizational

The RIA system is likely to affect the activities such as work that occur in the organization, organizational processes, and the roles that people in the organization play. These issues raise the question of how we can optimize the existing organizational structures/working practices, etc., to make best use of a new RIA system in an existing organization. Although the issues in this category may not arise for every RIA system, they are likely to arise for any RIA system that is implemented at the level of an organization.

See A.5 for more examples of issues associated with RIA systems at the organizational level.

7.6 Social/cultural/ethical

RIA systems will not operate in isolation, but within a social and cultural context. An effective RIA system will seamlessly integrate within that context, as a familiar member of the team or a cooperating entity. Behaviours of an RIA system should be expected, fitting social and cultural norms. The issues in this category describe how the design of an RIA system can impact the social interactions, group attitudes and motivation, and collective group behaviours positively or negatively, depending on how seamlessly the system fits within the social and cultural context.

See A.6 for more examples of social, cultural, and ethical issues.

7.7 Emergent societal

The widespread or strategic use of RIA systems will re-define humanity's relationship to technology. In the longer-term, intelligent agents can be employed to make important decisions about governance. Assurances about the data and algorithms used, and how they are governed is likely to be a concern.

There will be sociotechnical issues related to how responsibility is allocated when large-scale intelligent agents are introduced. It is possible that humans will only be assigned work that compensates for incomplete autonomy, possibly resulting in roles that are not enriching, engaging, etc., and in which humans are not maintained sufficiently in the loop to be effective to step in if needed. There can be changes in employment brought about by the replacement of knowledge-based jobs with automated systems, in a similar manner to industrialization replacing skilled manual workers in the 19th and 20th centuries, but with the additional consequence that the higher-level cognitive skills that are lost can take generations to reproduce, should the need arise.

See A.7 for more examples of emergent societal issues.

8 Ergonomics and RIA systems

8.1 General

This clause introduces ergonomics as a way of tackling human-RIA system issues. RIA systems will be more connected, complex, probabilistic and non-deterministic, social, and augment human capabilities well beyond merely replacing physical work. Interaction with these agents can become a relationship, their interface a personality, and users and agents can form complex human-machine teams, working together towards a shared goal.

The benefits and problems identified in 8.2 and 8.3 will exist in the context of humans interacting with non-human systems. Ergonomics continues to be relevant, but with changing proportions of methods and techniques appropriate to these new RIA systems (see Clause 7).

RIA systems require consideration of the entire system design. The changes in the nature of tasks and the design of work to accommodate the complex, social human-machine interaction of RIA systems are fundamental for ergonomics. These changes will require that ergonomics addresses the systems approach, adapts its best practices and expands into areas of psychology and other social sciences that ergonomists do not deal with on a regular basis at present.

8.2 Benefits of ergonomics applied to RIA systems

Ergonomics has improved the usability of mechanical and computer controlled automatic systems. There are benefits to be had if an ergonomic approach is taken in support of the design and introduction of RIA systems. Systems and products with high levels of human-centred quality tend to be more successful both technically and commercially. RIA systems developed and introduced following human-centred principles will offer several more benefits. These include:

— improved ability for user/human to take control when required;

— increased accessibility for people with a range of capabilities;

— improved user experience;

— improved acceptance and integration of RIA systems in human teams;

— improved integration and support of human tasks and activities; and

— improved system performance across all RIA system states [primary/normal, degraded, emergency, and reversionary (when the system is unavailable)] and during the transitions between these states where particular issues can arise.

That can lead to:

— increased acceptance of the product/system/service;

— increased confidence and trust in the product/system/service;

— reduced supporting costs;

— a competitive advantage; and