

Contemporary Ergonomics and Human Factors 2017

Editors: Rebecca Charles & John Wilkinson



Chartered Institute
of Ergonomics
& Human Factors

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A Vision for the Future of Radiotherapy

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Abstract. This paper describes how a suite of research techniques were used to inform the development of a vision for the future of radiotherapy. The aim of the vision was to conceptualise a next-generation radiotherapy system that creates a step-change in system performance. The impact of the vision on patient and HCP experience, safety, and efficiency were all explicitly considered and measured. The vision was used to inform the design of Elekta's release of Atlantic – a high-field MRI-guided radiation therapy system.

Keywords. Medical, Healthcare, Design, Radiotherapy,

1. Introduction

Radiotherapy is a safety critical and highly demanding treatment. From a patient perspective, it represents part of an incredibly emotional journey as it is typically associated with life changing conditions. Health care professionals (HCPs) working in radiotherapy have a challenging, multifaceted role. The emotional and physical needs of patients need to be carefully balanced alongside the requirements of efficiency placed on them by healthcare systems which are often under pressure.

Current radiotherapy systems have evolved and been optimised over many years. Successive innovations have improved the accuracy of the treatment and reduced the likelihood and severity of complications. This iterative journey of improvement has been punctuated by a series of step-change innovations, most notably in imaging, that have impacted the type of treatments that are possible and the way that these are delivered.

When a new product is based on a paradigm shift in technology the observation of legacy equipment only provides a partial picture. New technologies provide new capabilities which, in turn, permit new ways of working (see Task-Artifact Cycle; Carroll et al, 1991). The design of the equipment, its human machine interfaces (HMIs), and its surrounding environment can each shape these possibilities and constraints. As with almost all design projects, exploring and understanding these relationships and constraints early in the design process allows the design to be evaluated and optimised before the cost of change in time and money escalates, potentially to prohibitive levels.

With this in mind, DCA supported Elekta in designing and developing a next generation suite of radiotherapy equipment at an early stage of the design process. While conceptual, these 'visions for the future' were grounded through: collaborative technical review; an extensive body of evidence collected from visits to seven treatment sites worldwide including sites in Belgium, Brazil, Canada, USA (see Figure 1 and 2); over 90 hours of observations from about 360 treatment sessions; and over 50 in-depth interviews with health care professionals, thought-leaders and system stakeholders.



Figure 1 – Observations in control room



Figure 2 – Observing equipment setup in treatment room

The data collected was analysed using a range of human factors tools to identify opportunities for improvement and, more critically, unmet needs. The hierarchy placed on these needs by different stakeholder needs were explicitly considered. This included the needs of patients, healthcare practitioners (HCPs) and healthcare providers (system owners). Extensive modelling of the current system and the measurement of its performance, were a critical first step to form a baseline of system performance. By measuring and estimating the performance of existing systems for efficiency, efficacy, errors, staff convenience and

patient comfort (see Figure 3), unique opportunities were identified for reshaping the system and its environment. It was also possible to quantify the potential impact of different aspects of new design ideas on these metrics.

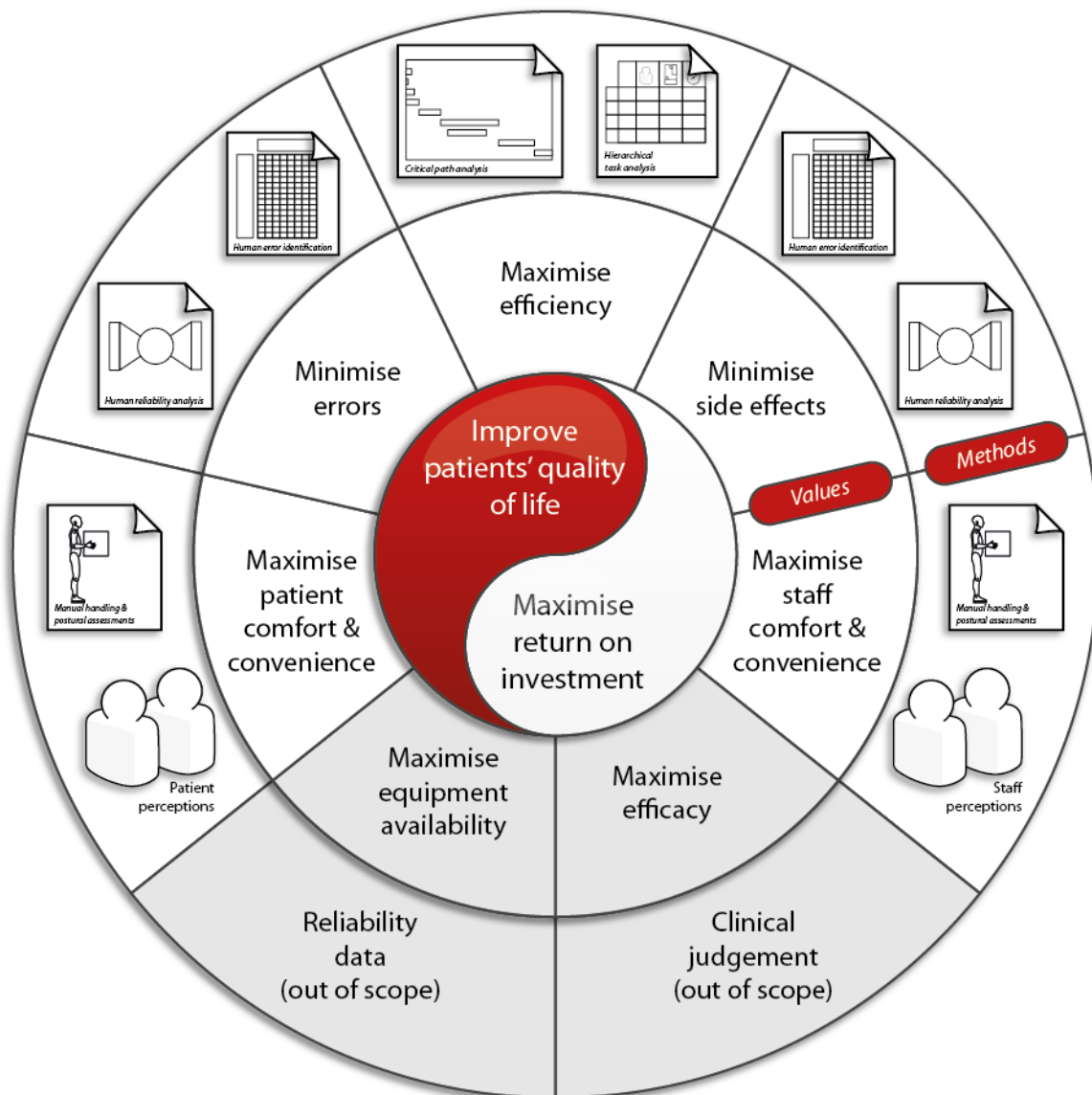


Figure 3 – Measures of performance and examples of tools used to assess them

1.1 The Atlantic system

One of the biggest challenges for providing unrivalled radiation therapy is the difficulty in visualising the tumour and surrounding anatomy in real time during treatment. Tumours can change shape from day to day, or move within the body up to a couple of centimetres even when patients are completely still. To compensate for the uncertainty of the tumour's shape and position, physicians need to include a safety margin, which means that they might also radiate healthy tissue. To minimise damaging healthy tissue, the dose per session is kept low and patients are treated over several sessions (Elekta annual report, 2015).

The Atlantic system utilises high-field Magnetic resonance imaging (MRI) to resolve these difficulties and further improve radiation therapy. From a beam generation and delivery perspective, Atlantic shares many common features with a conventional linac such as

Elekta's existing Versa HD product). The shape of the radiation beam is accurately adjusted by multi-leaf collimators to conform to the shape of the treatment site.

Like a conventional linac, the Atlantic system contains a feedback loop based on real-time imaging. However, the notable innovation of the Atlantic system lies in the way that the image is collected. Today's image guided radiotherapy (IGRT) is based on X-ray scans similar to CT (computed tomography) scans. While CT scans are relatively adept at differentiating between bone and soft tissue, MRI allows greater differentiation between soft tissues. The increased fidelity of the images is expected to be particularly useful in treatment such as kidney, cervix, pancreas and rectum. Also, unlike CT scans, MRIs do not expose the scanned tissue to radiation as part of the imaging process. This allows multiple or continual imaging throughout the treatment process for improved monitoring and adaptive planning, potentially leading to real-time planning updates.

By using MRI as an imaging technology, Atlantic offers two core advantages: increased accuracy and precision; and treatment adaptation i.e. motion, shape and biology. This enables physicians to reduce the safety margin, increase the dose per session, and eliminate the tumour with fewer visits to the hospital. This will reduce costs and be much gentler on the patient.

2. The research process

The first stages of the design process involved working with identified stakeholders (including key members of the Elekta Team, clinical specialists, health care providers and purchasers) to define key measures of system performance that are bespoke to the project. These were defined as system efficacy, efficiency, safety (staff and patient), user experience (staff and patient) and resilience (see Figure 3). Understandably, different stakeholders placed different priorities on each of these values; however, each was considered an important factor in decision making. A framework of tools and techniques was then constructed to allow the identification of objective measures of each of the performance values. These metrics of system performance were considered critical in driving an evidence-based approach to design. The overarching philosophy was to first measure the performance of existing radiography systems. This assessment would be used in two ways: to identify opportunities for improvement; and to form a baseline to measure design concepts against.

The resultant framework of tools used to populate these metrics (see Figure 4) can be broadly divided into two types: descriptive and formative. Descriptive tools, such as task analysis (Annett et al, 1971) and link analysis, were used to describe current activity within existing radiotherapy units. These models were also used to assess the impact of evolutionary changes i.e. adjusting size, shape, speed and performance of existing system component types. More formative tools, such as those from the Cognitive Work Analysis framework (Rasmussen et al, 1994), were better placed to describe the impact of radically new technologies and approaches.

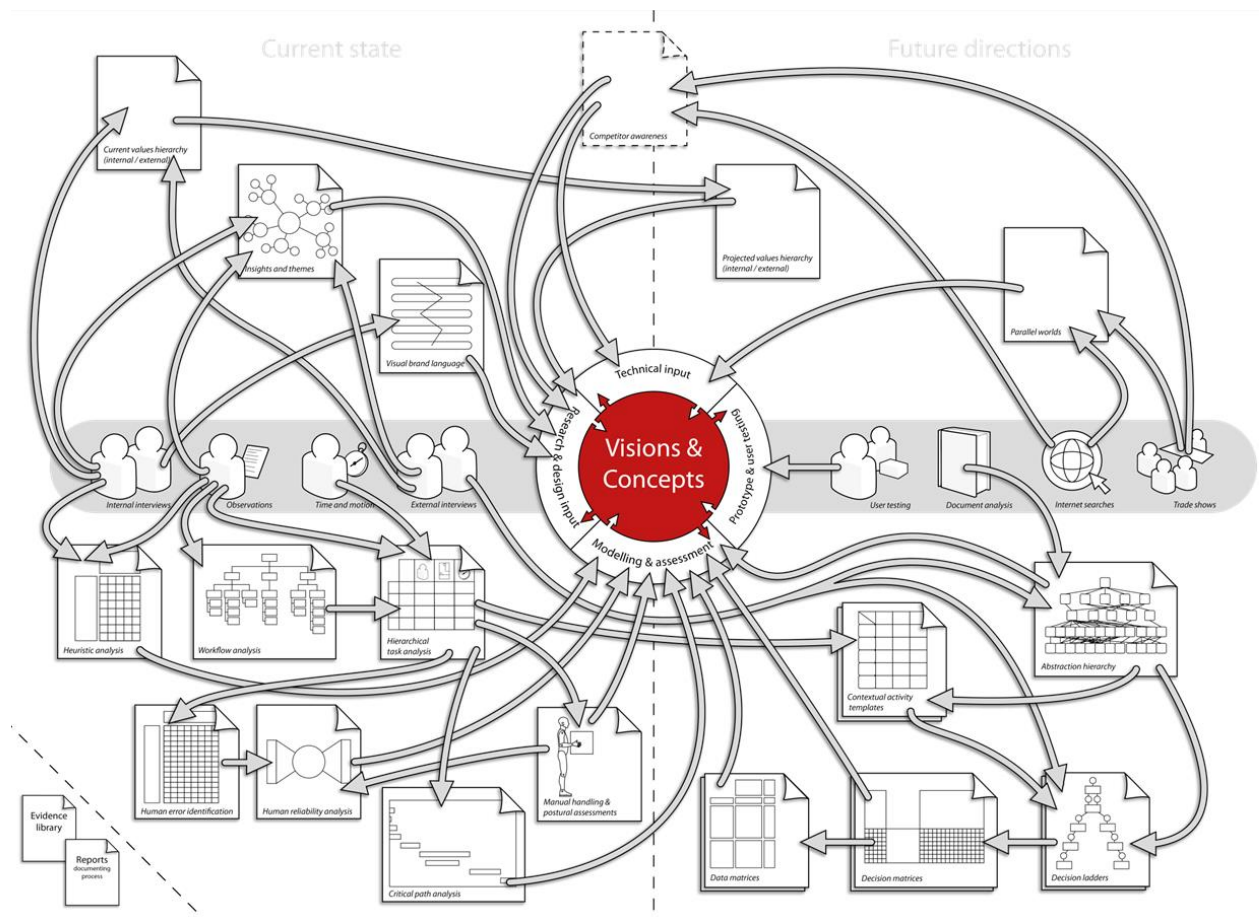


Figure 4 – Techniques applied to inform the vision

Hierarchical Task Analysis (HTA; Annett et al 1971) was central to the structure of the descriptive approaches. HTA provided a common task description that could be used in a range of compatible tools and techniques. These included: time and motion assessments through critical path analysis; control layout assessments using link analysis; human error identification using the Technique for the Retrospective and predictive Analysis of Cognitive Error (TRACER; Shorrock & Kirwain, 1994); and manual handling assessments using Rapid Entire Body Assessments (REBA; Hignett & McAtamney, 2000) and the manual handling assessment chart (MAC; HSE, 2004). The outputs of the error identification exercise were then explored in greater detail using a range of error assessments techniques. Probabilistic error assessment and reduction was conducted using HEART (Williams, 1986) and THERP (Swain & Guttman, 1983). To balance the known limitations of these techniques, more contemporary views on error were also adopted, such as CREAM (Hollnagel, 1998) and FRAM (Hollnagel, 2004).

Formative methods from Cognitive Work Analysis were used to explicitly relate the performance of physical objects to the higher-order system values (abstraction hierarchy) and to explore decision making and information requirements (decision ladders). A description of each tool used and its value to the project is presented in Table 1.

Table 1 – Human factors tools used in the project

Tool used	Value to the project
Hierarchical task analysis (HTA)	HTA provided a common description of the treatment workflow. A generic model was developed and used to explore variation between sites.

Critical path analysis (CPA)	Activities from the HTA were plotted in PERT charts. These were used to determine the critical path and identify design changes that reduced the overall treatment time.
Link analysis	Link analysis was applied in two ways: (1) In the physical space to explore how HCPs were required to move around the room during a treatment session. The arrangement of equipment and information was reconfigured to reduce the footfall required; (2) To explore the way HCPs navigated around the digital environment within the control room. Optimal workflows were identified as well as those that encouraged users to scan past CCTV footage.
Human error prediction (TRACer)	Keywords from TRACer (other keywords such as SHERPA would also be appropriate) were applied to each base-level task from the HTA with the aim of identifying low frequency 'errors' that were unlikely to be observed.
THERP & HEART	Probabilistic risk assessment tools were used to identify the hazardous events. Error producing conditions were used as design cues to identify control measures.
CREAM	The common performance conditions within CREAM were used to explore the differences between different sites. Notably differences were identified between sites in the USA and those in Brazil.
FRAM	FRAM was used to: (1) explore the interdependencies between tasks and operations within the treatment workflow; and (2) identify operations with the potential to have a significant impact on system performance.
Manual handling (REBA) & Manual handling (MAC)	Manual handling assessments were conducted based on still images from video footage using two cameras at orthogonal angles. Postures were rated using REBA and MAC. Manual operations were then rated as high, medium or low risk and used to prioritise and inspire design changes. Anthropometric tables were used to set acceptable design criteria.
Abstraction hierarchy (part of the CWA framework)	The abstraction hierarchy was used to: (1) model the higher order system values identified through the stakeholder workshop; and (2) explore, through a series of means-ends-link, the impact that the introduction and modification of physical objects within the system would have on them.
Cognitive activity template (part of the CWA framework)	The contextual activity templates were used to explore the flexibility and resilience within the system. The table explores which functions can take place in which situations and questions these constraints.
Decision ladders (part of the CWA framework)	A structured approach based on the use of decision ladders, was used to develop a comprehensive list of information requirements. These were coded to indicate when and where information is required, who needs access to it and in what format. This approach led directly to the design of information displays throughout the control and treatment room.

This research framework was the foundation of an evidence-based approach to design that allowed physical component performance e.g. the height range of the couch, to be directly related to high level measures of performance i.e. efficacy, efficiency, safety, experience and resilience. Robust estimates were made of the impact of different design changes and used to systematically prioritise them. This resulted in a concise summary of the performance impact for the resulting design concepts.

3. Result

The final vision addressed the design of equipment, accessories, digital displays and their interaction, as well as the surrounding room, control room and overall patient experience. From a patient perspective, the vision sought to minimise the physical discomfort and the emotional strain of the procedure. The ambiance of the room was designed to strike a

delicate balance between a welcoming and relaxing environment and one that instils confidence by communicating clinical excellence. It offered customisation of lighting and projection, and of ambient music. The patient treatment couch was designed both for comfort and support during loading, unloading and treatment, and for technical requirements such as alignment, accuracy and compatibility with MRI technology.

From a HCP perspective, detailed assessment of information requirements resulted in a design that provides the right information, at the right time, in the right place, to the right people, in the right format. This involved presenting information that is relevant to the treatment based on the specific step in the treatment process. This information is distributed so that it remains as close to the point of use as possible, whether that is in the control room, on the equipment, on the couch or accessories or a combination of these. By allowing the system to differentiate between user types e.g. HCPs, physicists and others, non-relevant information can be hidden and relevant information can be presented in meaningful ways. The type of information and the way it is displayed is customised, providing clear advantages for usability, efficiency and safety.

Intelligent feedback mechanisms allow the system to detect the stage in the treatment process and can detect non-conformance to predefined setup plans. Likewise, the layout of the room and the location of equipment were based on the HCP workflow, reducing the need for manual handling and excessive footfall. This focus also translates to the control room with workstations designed to support a vigilant task as well as meeting the requirements of operators moving between the control and treatment rooms.

3.1 Assessing the impact

Through detailed time and motion studies and critical path analysis it was possible to optimise the task flow in the vision resulting in an increased throughput of c.40%, and reduced footfall of c.50% compared to the current systems. The potential for error was controlled through the addition of engineered safe guards and recovery measures, and consideration of performance shaping factors. The control of information was found to be central to the resilience of the system. A careful balance was sought that utilised selective benefits of automation while ensuring that operators remained engaged and ultimately responsible for safe and effective treatment delivery. The presentation of information was optimised to: reduce the need to memorise setup instructions; change location to access information sources; or search for relevant information.

When combined with the inherent advantages of the high-field MRI-guided radiation therapy system, the usability and industrial design optimisations create a vision of the future that offers considerable advantages to all key system stake holders, in particular patients and HCPs.

4. From vision to reality

Human factors remained a key factor in the development of the Atlantic product. Further ethnography activities were conducted in additional markets including China, focusing on exploring the workflow, time and motion studies, and stakeholder perceptions. These were used to expand the existing evidence-base used to inform the vision.

To gain greater confidence in the largely desk-based anthropometric studies used to inform the vision, physical medium-fidelity rigs in the form of full-sized wooden spatial representations were developed. These were used to explore interactions in greater detail between: patient and equipment; HCP and equipment; and Patient and HCPs. Initially,

paper-based representations of screens and controls were used within the re-configurable rigs to optimise the location of controls and feedback displays. Theoretical assumptions around text heights and locations were also explored in context. As the design of the HMI developed, prototype fidelity was enhanced using dynamic interfacing on tablets. Gradually increasing fidelity throughout the process allowed fast iteration in the early stages of the design towards a convergence on a preferred embodiment.

The rigs were also used for role-playing different treatment scenarios to explore how the design supports different workflows. Stakeholder workshops were used to: refine the information requirements model; and differentiate between essential and non-essential information, and control interactions.

5. Discussion and Conclusion

This case study is a relatively rare example of how an extensive suite of human factors tools can be applied to a design problem at a conceptual level. Each of the different tools brought new insights that shaped the design.

Ethnography and interviews dominated the data collection activities and formed the foundation for most of the analyses, as well as being a rich source of inspiration. The more analytical approaches also provided a critical part of the process. Despite over 90 hours of clinical observations, a sizable number of predicted situations and ‘hazardous events’ were not observed. So these were validated during in-depth interviews with HCPs. The majority were rated as credible showing that considering them in the design was very important.

Quantification of performance, particularly error, remains a contentious issue within the human factors community. However, in this case it proved to be a rich source of valuable insights with the real value lying in the relative probabilities that allowed prioritisation to take place, and not in the absolute probability or error per se. Perhaps most critically from a design perspective, the explicit consideration of performance shaping factors served as an excellent design cue. More contemporary tools, such as CREAM and FRAM, were used to balance the known weakness of probabilistic risk assessment. The ‘common performance conditions’ from CREAM was particularly valuable for exploring the differences between installations in different geographical and regulatory contexts. FRAM provided a useful description of the interdependencies of actions, activities and interventions.

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