Facilitating the incorporation of HF practice in a corporate design process through qualitative and consensus analysis

Esther S. Smit

Supervisors: Dr. S. Borsci & Prof. Dr. J.M.C. Schraagen, University of Twente

L. Berkhout MSc, Thales Hengelo BV

Author Note

Contact email address: essmit21@gmail.com

THALES

Goedkeuring Stage-/Afstudeerverslag van:

Naam: Esther Smit

Titel verslag: Effective and future-proof: an adapted Human Factor approach to the design process

Opleidingsinstelling: Universiteit Twente

Stage-/Afstudeerperiode: 1-2-20 t/m 30-6-20

Vestiging/Afdeling: Hengelo

Stagebegeleider Thales: Linde Berkhout

Dit verslag (zowel de papieren als de elektronische versie) is door de begeleider van Thales Nederland B.V. gelezen en becommentarieerd. Hierbij heeft de begeleider de inhoud beoordeeld en gelet op de gevoeligheid daarvan, evenals die van daarin opgenomen gegevens zoals plattegronden, technische specificaties, commercieel vertrouwelijke informatie en organisatieschema's waarin namen staan vermeld. De begeleider heeft op basis daarvan het volgende besloten:

- [x] Dit verslag is **openbaar (Open)**. Een eventuele verdediging kan openbaar plaatsvinden en het verslag kan worden opgenomen in openbare bibliotheken en/of worden gepubliceerd in kennisbanken.

- [ ] Dit verslag en/of een samenvatting hiervan, is **beperkt openbaar (Thales Group Internal)**. Het zal uitsluitend door docenten en indien nodig door leden van de examencommissie of visitatiecommissie worden gelezen en beoordeeld. De inhoud zal vertrouwelijk worden behandeld en niet worden verspreid door middel van publicatie of opname in openbare bibliotheken en/of kennisbanken. Digitale bestanden worden onmiddellijk na het afstuderen verwijderd van persoonlijke IT middelen, tenzij de stagiair expliciet toestemming heeft verkregen om deze bestanden (geheel of gedeeltelijk) te behouden. Een eventuele verdediging van de scriptie kan **beperkt openbaar** plaatsvinden. Uitsluitend familieleden tot en met de eerste graad, en docenten van de vakgroep ....*<naam vakgroep>* mogen de verdediging bijwonen.

- [ ] Dit verslag en/of een samenvatting hiervan, is **niet openbaar (Thales Group Confidential)**. Het zal uitsluitend door de begeleider binnen de universiteit/hogeschool, eventueel door een tweede lezer en indien nodig door leden van de examencommissie of visitatiecommissie worden gelezen en beoordeeld. De inhoud zal vertrouwelijk worden behandeld en op geen enkele wijze worden verspreid. Het verslag wordt niet gepubliceerd of opgenomen in openbare bibliotheken en/of kennisbanken. Digitale bestanden worden onmiddellijk na het afstuderen verwijderd van persoonlijke IT middelen. Een eventuele verdediging van de scriptie dient **besloten** plaats te vinden, d.w.z. uitsluitend in aanwezigheid van stagiair, stagebegeleider(s) en beoordelaars. In voorkomende gevallen moet een aangepast verslag voor de opleidingsinstelling worden gemaakt.

THALES GROUP INTERNAL

THALES

Akkoord:

(Stagebegeleider Thales)

Akkoord:

(Opleidingsinstelling)

19-06-2020

(plaats/datum)

(kopie security)

THALES

Abstract

Thales Hengelo noted that Human Factors (HF) got increased attention from their customers. Thales' need for a structured, improved HF process that complements their design process and focuses on internal maintainers became more apparent. The request was thus to consider their current HF approach and propose recommendations to improve so that it would be effective, future-proof and applicable. This study is aimed at providing Thales Hengelo with such recommendations and is divided into three phases. Starting from the set requirements, the first phase consists of a theoretical background. The output of this phase was to lay a theoretical foundation when integrating HF. The second phase consists of mapping the current HF process within Thales Hengelo through reviewing internal documentation and interviewing stakeholders. The current process is explained, and recommendations are given. The third phase is aimed at reaching consensus on the recommendations. This was done through an offline questionnaire, an in-depth interview, and an online survey. Results are presented, followed by a general discussion of the research. As most recommendations were deemed applicable by respondents, the final result is a well-evaluated list of recommendations for Thales Hengelo. These recommendations can be implemented to form a structured, future-proof effective HF process.

Keywords: Human Factor Integration, Human Factors in Design, Human Factors in Maintenance, Thales Hengelo

Introduction

The Thales Group operates in several markets, ranging from transportation to safety and from cybersecurity to space. As a subsidiary of the Thales Group, Thales Hengelo (located in the Netherlands) operates in the Defense Industry, focusing amongst others on the design, manufacturing, testing and integrating of sensor systems. This ranges from sensors to track and search radars. Thales Hengelo claims the global market leader position, employing approximately 1600 employees as of 2019 ("Wie zijn wij?", n.d.). Innovation is therefore a key value to both the Thales Group as a whole and to Thales Hengelo as well. Keeping track of the current trends in the field is a necessity; one of these trends is an increased attention from customers towards Human Factors (HF). More and more of their customers require compliance to the HF standard of MIL-1472-G_CHG-1 (US Department of Defense, 2019), and are aware of usability aspects in the designs they acquire. Therefore, Thales Hengelo requested a study done on their HF process. Specifically, they want to find the answer as to whether there is room for improvement on their current HF process, or whether a new HF process should be implemented, and what that should look like. Recommendations for this process should be future-proof, feasible, and effective. From this, the goal of the study is formulated as finding feasible, effective, and future-proof recommendations for the HF process within Thales Hengelo. This study aims to identify barriers and obstacles towards integrating HF in a corporate setting, enriching the understanding of HF integration to the field of HF as a whole in the process.

Roughly, there are two types of users within the context of Thales Hengelo products: operators and maintainers. Operators are those who are using the product daily in the surroundings of their workplace; they know how to gather the necessary information. Usually, they use software developed either within Thales Hengelo as well, or another program, and have only a small-scale role to play concerning the hardware. Maintainer user groups are the other users. They access the hardware when maintenance is due or when an error arises which cannot be solved through the software. These maintainers can be staff from the client, or staff from Thales Hengelo, depending on the agreed upon maintenance level within the contract. Software development and hardware design are treated as separate processes within Thales Hengelo. Maintainers are usually trained internally on the hardware of the products. This report will focus on the maintainers as a user group, and therefore on the design of hardware as well. It should be noted however, that not all hardware parts can be adjusted to facilitate the HF of the maintainers; some of the components are bought from others, of which Thales Hengelo has no say in the design. The focus of this report is on these maintainers internal to Thales Hengelo. Although the request for a well-rounded HF approach is fueled by external customer demands, the HF approach inherent to Thales Hengelo focuses first on their internal maintainers. This ensures that the HF approach of Thales Hengelo fits their maintenance activities first. On the long-term, this can be expanded to other internal users as well.

This report is divided into three phases. Starting from the set requirements, the first phase consists of a theoretical background, detailing theories and models on HF integration into a corporate setting. This is done in order to find applicable HF practices, and to lay a theoretical foundation. The phase is aimed at emphasizing the importance of HF integration within companies, and to gather knowledge to avoid pitfalls. Barriers towards HF integration are identified here.

The second phase consists of mapping the current HF process within Thales Hengelo. Internal documentation and interviews with stakeholders were used as a method to map the current HF process and identify HF needs from the stakeholders. Barriers identified in the first phase are determined here for their applicability; that is, it is assessed as to which barriers are present within Thales Hengelo. The current process is fully explained. Recommendations based on the results of these methods are then given. Finally, the results are discussed.

The third and last phase is aimed at reaching consensus among the involved participants on the recommendations given. The method employed consists of an offline questionnaire, an in-depth interview, and an online survey. Results of the methodology are presented as well, followed by a general discussion of the research as a whole.

The structure is visually summarized in Figure 1.

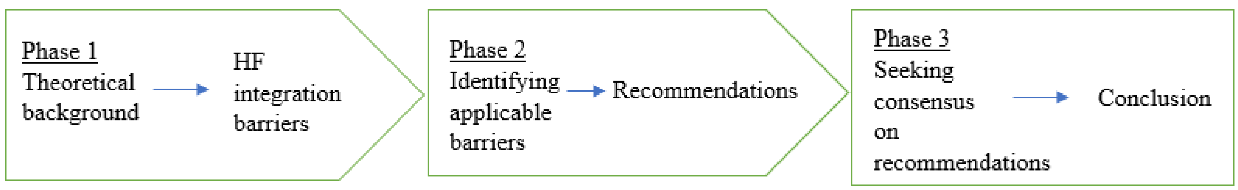

Figure 1. The three phases of the report with main component, and the result of the phase, which ties into the next phase.

1. Phase 1: From the requirements to key elements for HF integration in companies

In order to adhere to the requirements of Thales Hengelo on effective, future-proof and applicable recommendations, a literature research is necessary. It will come as no surprise that such an integration effort has various aspects which must be considered before designing and implementing a new or improved HF process for Thales Hengelo. The recommendations should therefore consider and if possible, address these aspects, so as to not clash and create any pitfalls or obstacles which stand in the way of an effective HF integration effort. This has already been noted by Waterson and Kolose (2010); they found several barriers standing in the way of successfully integrating HF in a corporate setting.

This phase is divided into three sections. First, there is a discussion of the theoretical background of HF integration, focusing on maintainers. Most HF literature consider a typical end-user, but little attention is given to maintainers. As maintainers are the end-users considered in this study, enhanced understanding from an academic perspective is desired.

Secondly, the relationship between risk and usability within the context of HF is also discussed. Examples are drawn from various industries. This can also provide insights as how other industries handle HF integration, and thus assist in forming the required recommendations.

Finally, the third section highlights the key elements seen in the previous two sections when it comes to HF integration.

1.1. HF integration

HF integration has been discussed thoroughly within the literature. The general consensus is that an early integration of HF within the design process is desirable (Abras, Maloney-Krichmar & Preece, 2004; Vredenburg, Mao, Smith & Carey, 2002; Kirwan, Evans, Donohoe, Kilner, Lamoureux, Atkinson & MacKendrick, 1997; Majid, Noor, Adnan & Mansor, 2010; Bødker & Buur, 2002), and that the integration effort is driven by both internal and external forces (Chua & Feigh, 2011). Importance of this early HF integration is vital, as Elm et al. (2008) state that only through a continuous HF process within the design process, systems can achieve their maximum potential effectiveness at the intersection of agent, technology and work. This allows the field of HF expertise to grow in practice. Implementing HF within a design process has the goal of allowing designers and other engineers to reach a comprehensive understanding of the capabilities and limitations of users in context of the planned tasks within a system (Cullen, 2007). Several attempts to integrate HF into various processes have been accomplished successfully and come with advantages such as cost savings (Burgess-Limerick, Cotea, Pietrzak

& Fleming, 2011), and improvements in the design of work systems (Village, Searcy, Salustri & Neumann, 2015).

However, although the importance of HF integration is acknowledged widely, this does not imply that there are no barriers or challenges. Several barriers are present which stand in the way of successfully integrating HF, which has been noted by Waterson and Kolose (2010). They argue that although the HF team was widely known in the examined organization, some barriers remained. They developed a framework which highlights social and organizational aspects on an individual, organizational, and team level standing in the way of successful HF integration and collaboration (Figure 2).

Figure 2. Framework indicating the social and organizational aspects of HF integration on an individual, team and organizational level (from Waterson & Kolose, 2010).

The framework indicates that attitudes, perceptions, support from higher organizational levels, the background of the HF team and the organizational standing of the team itself are all barriers which oppose successful HF integration. It is therefore vitally important to identify barriers relating to the corporate setting in which an HF integration effort must be made.

The barriers identified in this framework have been found in other studies as well. Vredenburg, Mao, Smith and Carey (2002) found that 32% of their survey participants could not say with any certainty whether a user centered design really caused a decrease in product development costs. They also found that the application and adoption of user centered design methods is done in varying degrees across different organizations. Additionally, their research found no measures regarding the effectiveness of user-centered design. Relating this to the framework, their findings relate to the barrier of the HF data problem, lacking precision. Their finding that there were no measures on effectiveness on user centered design might be a cause for the identified barrier of lack of support from higher organizational levels. In another study by Poltrock and Grudin (1994) who investigated two cases of interface design, it was apparent that in one of the cases it was not clear whose responsibility it was to maintain customer contact, so that user requirements could be derived. Looking at the framework, this might be due to the HF team being low in the organizational hierarchy, and not having a good overview of the duties expected from them in that regard.

It is clear that in order to successfully integrate HF within a corporate setting, the applicable barriers need to be identified. Across different companies, not all barriers might be present; and some might be more present than others and therefore require more attention in order to mitigate them.

Looking at the user level, not only the end-users and organizations but maintainers stumble upon problems as well. Metrics derived from the HF field on maintenance effectiveness reveal little knowledge on real-world needs of maintainers (Galar, Stenström, Parida, Kumar & Berges, 2011), again relating to the barrier of the HF data being different than from other engineering disciplines. Another finding relates to the barrier of organizational culture. Gawron, Drury, Fairbanks and Berger (2006) note that the usage of an error reporting system within the aviation industry helped overcome psychological and cultural barriers when the pilots were not imposed with sanctions. In other aviation companies, there are error management systems in place for maintainers as well, although there is still a barrier as maintainers have a fear of punishment, which raises the question on how to encourage maintainers to report incidents (Hobbs, 2008). This could be overcome by implementing a 'just' culture, where only the most major errors due to maintenance are disciplined (Hobbs, 2008), however, this implementation will only have an effect on the long term as such culture change is hard to achieve. A more immediate solution comes in the form of training aviation maintenance personnel on human factors, specifically, to raise their awareness on the discipline and to change their attitudes to the field as well (Hobbs, 2008). The barrier of the HF data being different is also present there; often, much importance is put upon statistics (Aurino, 2000), however, this might not be the most suitable metric for safety because cultural differences as well as context cues play a large role. This explains why HF data is seen so differently from other types of data as apparent in the framework of Waterson and Kolose (2010).

Based on an extensive literature review by Sheikhalishahi, Pintelon and Azadeh (2016) on maintenance in the field of HF, three domains within the literature focusing on maintainers have been distinguished. These are the physical, cognitive and organizational domains. The physical domain of HF in maintenance focuses on human anatomy and safety, the cognitive domain on mental processes ongoing when carrying out maintenance activities, and the organizational domain considers the social-technical systems as well as communication and quality management. A clear distinction between the different maintenance activities and aspects from their job context is advocated here. Understanding that all these domains have an influence on maintenance activities is thus the key towards successful HF integration. This notion is further illustrated by the Swiss Cheese Model as developed by Reason (1990), which distinguishes the categories of physical, cognitive and organizational and their interplay as well (Figure 3).

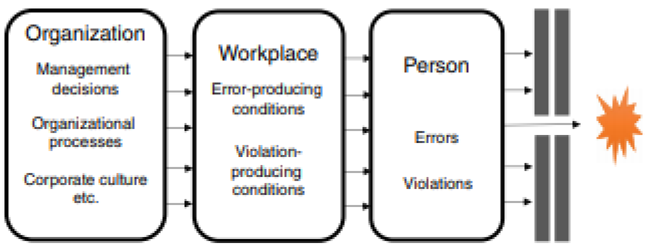

Figure 3. Combining the three literature categories in the Swiss Cheese model. From Sheikhalishahi, Pintelon and Azadeh (2016).

The model in Figure 3 shows how the different fields interact, with as a possible consequence an accident. It is therefore necessary to consider these fields as a coupled system as opposed to separate entities. This multi-faceted approach has been supported by the literature review of Simões, Gomes and Yasin (2011), where the authors note that there is a shift within the literature from purely viewing maintenance activities within the context of HF from a budgetary perspective to a more systematically, organizational point of view of said maintenance activities. This shift of perspective and the aforementioned notions on the different domains of maintenance activities is argued to reduce errors (or risk) (Sheikhalishahi, Pintelon & Azadeh, 2016).

As for the barrier of regarding HF as expensive, shown by the framework of Waterson and Kolose (2010), it is difficult to come up with justification regarding the effectiveness of HF, as cost-benefit studies on HF are difficult to conduct (Beevis, 2003). However, user feedback can change this. Through comparing the user feedback over various similar products, a conclusion can be drawn as to whether HF really brought about a change in the user experience. This user feedback can then be collected and used for further reference, as is proposed by Karsh, Holden, Alper and Or (2006) within the field of medical engineering. They present HF engineering as a paradigm complementing the other paradigms inherent to patient safety. According to the authors, these are a focus on reducing healthcare professional errors, reducing patient injuries and improving the use of evidence-based medicine. The authors argue that HF engineering can be modelled according to three phases, being performance input, transformation processes and performance outputs. A feedback loop connects the phases and makes it iterative. Each phase consists of relevant information, such as the environment, cognitive performance and organizational factors. This ensures that there is a focus on both the healthcare professional and the patient (Karsh, Holden, Alper & Or, 2006). This proposed process bears similarity to another model by Money, Barnett, Kujis, Craven, Martin and Young (2011). This model has phases such as identifying requirements by identifying user needs and refinement of a concept design. Then, these requirements are met through designing the device and gather evaluations to serve as feedback and another input to the first phase of identifying requirements. Again, the different aspects surrounding the user are considered, and are emphasized by means of a feedback loop. The feedback can be collected to assess whether changes in usability aspects have a better impact on the users of the design.

It has become abundantly clear that in order to proceed with integrating HF, barriers need to be considered, as well as the different aspects surrounding the users or in this case, the maintainers. Both the framework by Waterson and Kolose (2010) and the findings from the literature review by Sheikhalishahi, Pintelon and Azadeh (2016) point to this notion. Industries are dealing with this in different ways; the aviation industry tries to mitigate their present barriers by an error reporting system, whilst in the medical engineering field, the use of feedback loops within the HF process is being employed. Thus, the processes, along with the aforementioned organizational and social aspects as well as the user context of Thales Hengelo need to be thoroughly examined.

All these methods, models and framework are means toward the same goal, which is error-reduction, amongst other goals. The concept of error-reduction is addressed through the relationship between risk and usability, on which the next section will elaborate further.

1.2. The relationship between risk and usability

The relationship between risk and usability is a tight one. Risk is seen here as the potential for error. Error can be defined as “a failure to perform an intended action that was correct given the circumstances” (Gawron, Drury, Fairbanks & Berger, 2006, p. 59). Of course, there are different levels of errors, which can be classified according to their cause and ranked according to the severity of the resulting consequence, which is dependent on context as well. If risk is reduced, the usability of a product will be moderated. This has been found by Belanche, Casaló and Guinalíu (2012), who tested the usability of a website. Their results suggest that when perceived risk is high, the role and level of usability becomes more relevant. Not only for websites, but in the field of medical engineering usability is present; numerous cases have been made to implement usability testing in order to prevent risks and errors (Fairbanks & Caplan, 2004; van der Peijl, Klein, Grass & Freudenthal, 2012). Thus, the relationship between usability and risk becomes apparent again: “usability problems in a device can increase the occurrence of use errors" (Bligård & Andersson, 2009, p. 10). Involving the user is a beneficial first step, however, care should be taken so that the context in which the user operates is taken into account (Shackel, 2009). Convincing upper management and other stakeholders on the importance of usability assessment might be difficult, as most benefits are usually not immediately apparent. This can be overcome by linking usability testing to risk management (Altom, 2007). Overcoming this obstacle is thus of importance to proceed with usability testing in order to reduce risk and resulting errors and support the relationship between risk and usability further. Through linking usability testing to risk management, the HF team could also rise up on the organizational ladder, as risk management is usually perceived as an important department. This mitigates the barrier in the framework of Waterson and Kolose (2010) of HF being on a low corporate branch. Additionally, the usage of standards and regulations may also serve as a tool inherent to risk management. Within the earlier mentioned medical device field, the US Food and Drug Administration (FDA) developed several guidelines on how to address HF through the design of medical devices. Some of these guidelines are bundled into the document 'Applying Human Factors and Usability Engineering to Medical Devices' (FDA, 2016). Therefore, using standards or guidelines can assist in mitigating the barriers identified by Waterson and Kolose (2010).

The previous section on HF integration made it clear that barriers exist when integrating HF. However, not all barriers may be present in the same level across industries or even companies. Illustrative of this is that the relationship between risk and usability is also being treated differently across industries. For instance, North (2015) indicates that usability is of high importance within the field of medical engineering, whereas Stark and Kokini (2010) note that the Defense Industry only regards HF as a means to reduce risks. This might be due to the nature of the industry: the integration of HF in a company related to the Defense Industry might be different from other industries, since the way in which the operations take place need to adhere to stricter guidelines (Waterson & Kolose, 2010). This is not to say that integrating HF in a company related to the Defense Industry is a lost cause; Booher (1997) describes several case studies within the domain of army systems where the integration of HF has been proven to be advantageous, noting that there have been increases in safety, performance levels and a decrease of associated costs. This has also been noted by the related governmental institutions. The US Department of Defense addresses the early integration of HF in the design process in MIL-HDBK-46855A (US Department of Defense, 1999), which complements the earlier established MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019; first version in 1968). This military standard specifies several HF design requirements on military equipment. Further attention from governmental institutions is described by Burgess-Limerick, Cotea, Pietrzak and Fleming (2011), who state that "formal HSI implementation programs have been established within the US DoD, and more recently in the UK MoD, as well as civilian agencies…" (p. 59). Thus, the Defense Industry acknowledges the field of HF becoming increasingly more important.

1.3 Key elements of HF integration

Summarizing, even though the importance of HF integration is widely recognized, it is not an easy feat to do so. Barriers within the organization on different levels as well as different aspects within the user context need to be considered in order to bring success towards the HF integration effort. Even the context of the industry itself in which a company operates reveals that HF can be seen as either risk-reducing, as is the case in the Defense Industry, or as means towards improving usability, as examples have shown in the field of medical engineering. Table 1 shows the recommendations gained from this theoretical background.

Table 1.

Recommendations for an HF approach derived from the literature

Recommendations	Source
Early integration of HF in the design process	Abras, Maloney-Krichmar and Preece, (2004, amongst others; for full list, see text)
Distinction between the different maintenance activities and aspects from job context	Sheikhalishahi, Pintelon and Azadeh (2016)
Use user feedback	Karsh, Holden, Alper and Or (2006)
Feedback loop within the HF process	Karsh, Holden, Alper and Or (2006)
Check how risk and usability are being treated; differs across industries	North (2015), Stark and Kokini (2010)

Early integration of HF in the design process has been emphasized greatly by different sources. This implies that the HFE should be involved as early as possible within the design process, so that changes improving HF can be met with relatively low resistance. Proposed changes later in the design process may be shot down as this cost too much or the product is in such a state that changes are difficult or impossible to implement.

The distinction between different maintenance activities and the fields such as cognitive and physical resonates with the framework by Waterson and Kolose (2010). Their framework points to barriers on different levels, and the maintenance activities are executed on different levels as well. From an HF perspective, it is thus important to handle HF integration across these different levels.

As for the HF process itself, the importance of feedback loops which may transport the user feedback across to similar products has been established by Karsh, Holden, Alper and Or (2006) extensively. This allows for having an impact through user feedback early on in a relevant design process, which ties in with the recommendation of having an early involvement from HF within the design process.

Finally, the relationship between risk and usability is being treated differently across industries. When a focus on risk is achieved, HF activities which focus more on the usability side can be conducted to restore the balance, or vice versa. HF activities thus needs to be tailored as to what aspect of this relationship is focused on the most within the industry at hand.

Next to the recommendations, barriers were identified as well. Table 2 summarizes these further.

Table 2.

Identified barriers of HF integration

Barriers	**Source**
Organizational structure: HF low in hierarchy	Waterson and Kolose (2010)
Organizational culture: 'engineering worldview'	Waterson and Kolose (2010)
Team performance: degree to which HF supports organizational goals or company business objectives	Waterson and Kolose (2010)
Team viability: sustainability of collaboration with other groups over time	Waterson and Kolose (2010)
Attitudes and perceptions: HF seen as expensive	Waterson and Kolose (2010)
Information and data problems	Waterson and Kolose (2010)
Rewards and recognition: lack of support from top managers	Waterson and Kolose (2010)
Training and education: HFE's have different background than other engineers	Waterson and Kolose (2010)
Convincing upper management of HF importance is difficult	Altom (2007)

The barriers are present on different levels. On an organizational level, there is the notion that HF is low in hierarchy, is not supported by top managers, information and data problems, and that the organizational culture does not allow room for HF as other engineering disciplines are seen as more valuable. Inherent to the HF team level is the degree to which HF sets to the organizational goals, the collaboration between other relevant departments, and the background of the HF team members. On an individual level are the attitudes and perceptions of the other departments. Several of these barriers such as the information and data problems and the attitudes and perceptions lead to the barrier that convincing upper management of the importance of HF remains difficult.

Although barriers have been identified within the literature, this is not to say that all of these barriers are present within Thales Hengelo as well. It is therefore necessary to find out which of these barriers pose a threat towards a successful HF integration effort within Thales Hengelo. This will be done in the next phase of this report.

2. Phase 2: Mapping the current process at Thales Hengelo

In order to address the barriers presented in the previous phase, and to identify whether these play a role within Thales Hengelo as well, it is necessary to map the current HF and design processes of Thales Hengelo. Additionally, asking stakeholders on their HF perspective could reveal crucial information not present in internal documentation. The goal of this phase is to assess the current situation at Thales Hengelo, and to generate recommendations which are applicable.

2.1. Method

In order to derive aspects and gather context data which reveal obstacles, challenges, and user contexts from the three different fields of organizational, cognitive and physical information, a thorough method with input from stakeholders is desired. In this phase, the method of Høegh (2008) is employed, with some adaptations. Høegh (2008) examined how to integrate usability activities in a software development company and conducted interviews, as well as observations and reading through internal documentation. As this relates to HF integration, this method is therefore highly relevant to this study as well.

The methodology used here consisted of reviewing internal documentation and interviewing relevant stakeholders.

2.1.1. Review of internal documentation. By assessing the current design and HF processes of Thales Hengelo, it can become clear whether the recommendations discussed in the previous phase are already present. For example, by mapping the processes it can be seen whether a feedback loop is already in place. Thus, an understanding of the current design and HF processes are aimed for.

The Human Factor Engineer (HFE) of Thales Hengelo pointed the researcher to relevant internal documentation, stored on the internal system Chorus. The HFE used the keywords "Human Factors", "RAMT process description" and a link-tree to arrive at the design process description. This yielded a total of 6 documents: an HF anomaly sheet, a manual detailing the HF process of another Thales specific unit, two PowerPoint presentations on HF within Thales context and their design process, and process descriptions on the design process of Thales Hengelo and its Specialty Engineering department. Due to a signed NDA by the researcher, these documents cannot be published with their exact title and content in this research.

These documents were carefully read through, and notes were taken by the researcher. The documents were used to build an understanding of the current process of Thales Hengelo and resulted in a figure, which summarizes the content of the reviewed documents, as well as an accompanying explanation. This can be used to check with the aforementioned recommendations of Phase 1.

2.1.2. Informal interviews. Other than recommendations, barriers were also found in Phase 1 of this report. These might not become apparent through internal documentation but could be discovered through interviewing relevant stakeholders. The aim of this method is thus to assess which barriers are present within Thales Hengelo.

The total number of participants for this method was eight, and all had different roles within Thales Hengelo. These are Test & Integration Manager, System Engineering Manager, Safety Engineer, Documentation Author, Customer Care Engineer, Logistic Engineer, Hardware Architect, and a Maintenance Intelligence Engineer. Their participation was voluntary. These stakeholders were selected for their relevance by the HFE. They were then approached via e-mail, asking them if they would like to participate in the study, explaining the goal of the study, and setting up an appointment. Characteristics such as age and gender of the participants are not available to the researcher due to confidentiality reasons.

The interviews with the stakeholders were semi-structured and focused on the description of activities during the design process, as well as any overlap with the HF domain. Specifically, the questions of “what is your role in the design process?”, “which relations to HF do you see?”, “what output from HF might be helpful to your work?” and “how often do you contact the HFE?” were asked and answered. Questions were chosen whilst keeping the goal in mind of gathering data from other disciplines regarding what they need from the HF discipline within Thales Hengelo. Furthermore, as the interviews could reveal complementary information of the current process, questions to uncover that sort of data were also focused on and used. Along with the questions, the goal of this method to the interviewees was also explained. This allowed participants to give additional information which might not have been covered by the questions asked. Interviews were conducted in Dutch; however, the questions and answers were translated after the fact. The full list of questions in English can be found in Appendix A. The duration of these interviews ranged from 30 minutes to an hour; follow-up questions or clarifications were obtained through email. Answers were recorded by means of taking notes, as audio or video recordings may prohibit participants from sharing project-specific details due to corporate confidential issues. Such details could give rich examples of for instance barriers between their domain and the field of HF and increase the understanding of any issues between the domains and HF.

2.1.3 Data analysis. Through these methods, qualitative data was derived.

The notes taken while examining internal documentation were summarized, compiled and shaped into an explanation, along with a figure made by the researcher. This was done by carefully reading through all the material first, taking notes and drawing out a draft version of the design process of Thales as more information was read through. Once there was a draft version, the researcher then dove deeper into the documentation to fill gaps within the draft and enrich it with further details. The draft version was then finalized with these details, as well as the accompanying explanation. The researcher then asked the HFE, who in turn reviewed the explanation and figure, and judged them as being truthful. The results of this deductive content analysis (Elo & Kyngäs, 2008) are presented below.

The notes acquired during the interviews were separated and sorted through via thematic analysis (Braun & Clarke, 2006), based on barriers and obstacles from the interviewee's perspective. First, the researcher read through the notes a few times, to get familiar with the data. Then, codes were determined posteriori and assigned per relevant comment of a topic. The quantity of comments relating to those codes were counted by hand after the procedure. For each code, some illustrative comments were selected to quote directly within the results section.

This resulted in a deductive thematic analysis, where codes were identified, and the frequency of the comments related to the codes were reported.

2.2. Results

2.2.1 Mapping of the current process

The internal documentation revealed the steps within the current design processes and the current activities within the HF process. These are visually summarized in Figure 4 and explained further in the text below.

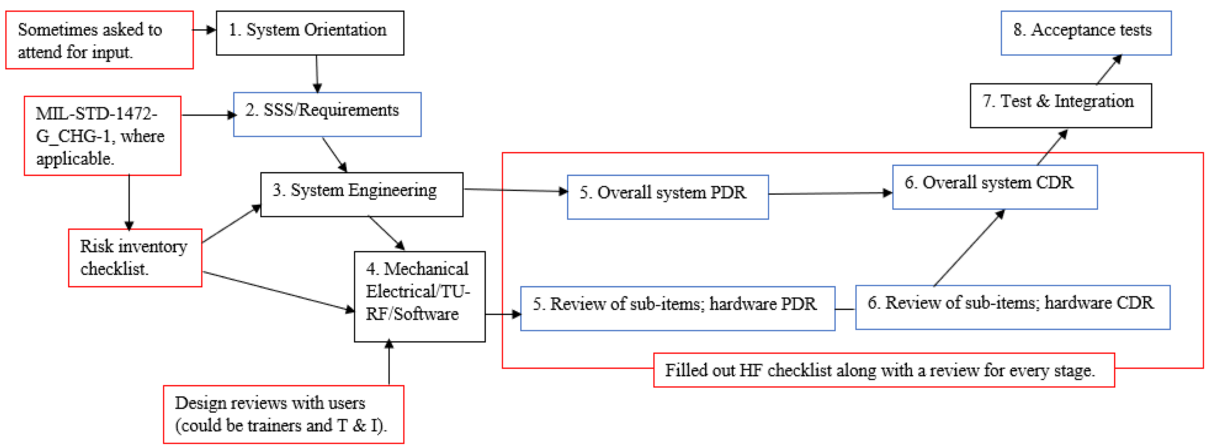

Figure 4. The current design process within Thales Hengelo. HF activities are outlined in red, steps in which a launching customer are involved are outlined in blue. The explanation below starts at the first phase, System Orientation, and follows the arrows all the way to the eight phase, Acceptance tests.

At Thales Hengelo, there is a distinction on the involvement of the external customer during a project. On the one hand there are launching customers, who, after asking for a bid, select Thales Hengelo to take on the proposed project, and may be involved during the project as well. On the other hand, there are customers who are interested in the sensors of Thales Hengelo and buy them after a project has finished; Thales Hengelo initiates these projects internally. Furthermore, customers differ, amongst other factors in the level of supportability, desired complexity of the systems, and market segments. This report mainly focuses on projects where a launching customer is involved; however, adaptations can be made to support a project timeline where no launching customer is involved.

Red blocks are the input from the HFE and stages where they are largely involved; black blocks are stages in the design process in which no launching customer is involved; blue blocks indicate stages in the design process with the involvement of the launching customer. The process follows the V-model (as developed by Forsberg & Mooz, 1991) consisting of feedback loops to keep in check with the specified requirements. These iterative loops can be of great value to this research, as human-centered design frameworks are most effective in design processes where incremental development takes place (McNamara & Klein, 2016). As mentioned before, feedback loops are of utmost importance as well in the field of medical engineering (Karsh, Holden, Alper & Or, 2006). The reader should note that the user considered in this process is the internal maintainer of Thales Hengelo.

Below follows a description of the process stages. Parallel HF activities are described as well. It starts with the first stage, system orientation, and follows the numbers in Figure 4 in chronological order.

1. System orientation. The first phase of the design process addresses the system orientation phase; the customer is having a problem which is identified, and a design needs to provide solutions and answers. The range of possibilities is explored here. Currently, the HFE is sometimes invited to these meetings to give their input.

2. System Segment Specification. The next stage focuses on System Segment Specification

(SSS), drawing up the requirements from various areas. The input from the HFE here is to provide the applicable and relevant requirements from the MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019), so these can be addressed and incorporated in the design as well. This is done by identifying relevant chapters, and determining whether these are used as mere guidelines, or should be complied. These are also applied to build to spec items, which are products used as parts within the systems of Thales Hengelo. These should comply to the requirements as well, however, Thales Hengelo cannot change these or produce them.

3. System Engineering. Moving on to System Engineering, the HFE checks the MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019) along with the design at that point, and identifies HF risks which could arise from the current design of the product.

4. Mechanical Electrical/TU-RF/Software. The identified HF risks flow into the Mechanical Electrical/TU-RF (Radio-frequency)/Software as well, where the design is further built. These risks can be assessed through design reviews with users; when no customer user representative is present, internal staff who are close to the actual end users are employed in these tests, usually trainers or employees from the Test & Integration department. The level of sophistication of the user test is dependent on resources, urgency and the foreseen problems with the design.

5. Preliminary Design Review. Both the System Engineering phase and the Mechanical Electrical/TU-RF phase then move on to the preliminary design review (PDR), which is on the overall system and the review of sub-items, respectively. When all the points which were brought up in the PDR are addressed in the design or are justified not to be incorporated into the design, the design process moves on.

6. Critical Design Review. The critical design review (CDR) again addresses both the overall system as well as its sub-items and hardware. The HFE fills out their checklist there, along with reviews for every stage; thus, a checklist and a review are filled out for both the PDR and the CDR. A review on the aspects related to HF with stakeholders is also conducted here, and the HFE also attends multiple reviews on the topic.

7. Test & Integration. The design moves on to the Test & Integration (T&I) department, which checks whether the design fits all the requirements which have been set. At this point, the earlier established HF checklist has been filled out by the HFE and serves as proof of compliance. Sometimes, when the T&I department finds points of improvement, this feedback is looped back to the HFE. However, this is quite informal and depends on the T&I employee, specifically, whether they know the HFE.

8. Acceptance tests. The final stage is the acceptance tests, where the first series of tests are conducted on the grounds of Thales Hengelo. Finally, the product is shipped to the customer to test whether the product can operate in their environment, set to the requirements made by the customer within acceptable margins, which were pre-specified.

Dependent on the agreed upon level of maintainability, the customer either carries out a high level of maintenance themselves, or employees from Thales Hengelo carry out the necessary maintenance activities during the lifecycle of the product.

2.2.2. Identified barriers within Thales Hengelo. Five common barriers were identified through the performed thematic analysis on the notes from the interviews. An overview of the identified themes and the number of participants identifying with that theme can be found in Table 3.

Table 3.

Number of participants mentioning the identified barriers

Theme	Number of participants (out of 8)
HF knowledge and awareness sparse	3

Usability requirements are not being considered	3
User feedback at the end of the process	4
Resistance to changes aimed at improving usability	3
HF practices and activities carried out in other domains	3

First, there is the notion that awareness and knowledge on HF is sparse and little within different domains. The HF knowledge is present, but it is minimized and scattered. This points to a clear need for an HF information hub. This has been noted by three out of the eight interviewed stakeholders. The Hardware Architect noted that the set moments in which all disciplines are gathered together to talk over the design are sometimes too sparse: “there is a need for a HF knowledge bearer who needs to be involved at all times…an active cooperation effort is needed. Something such as a database on HF which we could access at all times would be valuable”. This sentiment was repeated by the Test & Integration manager: “often, we are not aware where HF begins and where it ends, there are certain guidelines but not everyone is aware of them”. The System Engineering Manager emphasized this: “there is a need for some sort of HF instruction in order to raise awareness about the domain. For which aspects do we need to involve the HFE?”

The second theme is that usability requirements are not being considered here. This was noted by three of the interviewed stakeholders. The Safety Engineer commented that apart from the requirements in MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019), there could be requirements for usability purposes. A tight cooperation between Safety Engineering and HFE is of importance there so that usability can be approached from both a safety and a HF perspective. However, as noted by the System Engineering Manager, HF goes further in set requirements than Safety does concerning the level of detail and the margins for compliance.

The third theme is that most feedback from actual users is being received at the end of the process, during stages in which the HFE is currently not involved. Four stakeholders iterated this. The System Technical Specialist, noted that it was necessary to involve HF earlier in the design process: “Some of the functions that are developed may not be used because either the customer doesn’t know that they are there, or they haven’t been involved in the process. Feedback from the users would be very valuable”. The Customer Contact Center Engineer implied that the involvement of stakeholders who are in direct contact with the customer is of importance: “Trainers and T&I personnel gain more information on customer feedback than we do as Customer Contact Center, also on HF-related things”. The Documentation Author iterated this, by commenting that they gain feedback from customers on errors in their manuals, or when a description in the manual is unclear when the customer carries out maintenance activities themselves.

Fourth, when changes to improve usability are proposed, these are sometimes met with resistance, depending on the level of budget, severity of the proposed change, and the benefits the change will incur within the design. Three stakeholders indicated problems of such sort. Incremental steps towards usability are usually not taken, unless costs to implement these are not too much. If it does cost too much, usually a higher-up is needed to sponsor the intended change. These changes are sometimes necessary, since it has been noted by a stakeholder that “there is a large gap between requirements and practice”.

Finally, there are some HF practices and activities carried out in some domains, however, this is not within all domains and awareness on these activities taking place in other domains is low, even though these can be convenient there as well. As of now, the researcher is aware of such activities being conducted within three different domains. The Documentation Author noted that they use user personas already, which assists them when writing descriptions of maintenance tasks and activities in the manuals. The System Technical Specialist said that scenarios were sometimes used in order to determine what the flows of action and decision-making are, which aids them in designing.

2.3. Generated recommendations

A continuous HF effort throughout the design process is advised (Elm et al., 2008; Landsburg et al., 2008; MIL-HDBK-46855A US Department of Defense, 1999). Thus, HF activities applicable to certain steps in the design process need to be identified and implemented. Furthermore, the applicable HF activities should cover the whole design process. MIL-HDBK-46855A (US Department of Defense, 1999) outlines several HF methods which can be conducted during various phases. In this section, a HF process which can be laid on top of the current V-model is outlined. Every HF step corresponds with at least one step or more in the design process of Thales Hengelo and provides valuable output for the other stakeholders involved. The major theme of this proposed approach to HF is the integration of the user or user representatives as to bridge the gap between theory and practice. This can also assist in thinking on what the user needs in practice. However, it is not advised to approach this from a one-size-fits-all perspective since not all projects, or in this case, products, are the same (Vredenburg, 2002). This implies that common HF methods need to be adapted to the context at hand. Methods proposed per phase need to be assessed for every project in order to determine their applicability and effectiveness for the project at hand. A selection can then be made from the list of proposed activities of those which reflects the project best, and which are the most feasible to conduct in the given context. Figure 5 shows the steps in the proposed HF process, as according to recommendations can be from MIL-HDBK-46855A (US Department of Defense, 1999). Added to this is the phase Aftercare, which will be explained in a later section.

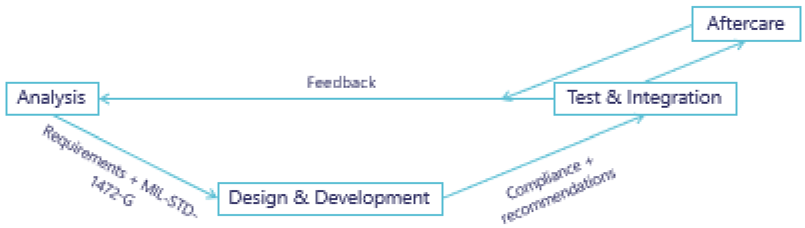

Figure 5. The proposed HF process.

As mentioned during the discussion of HF integration in the first phase of this report, a HF approach needs to have a clear feedback loop, and take into account the user requirements (Karsh, Holden, Alper & Or, 2006). This proposed process fulfills both those conditions. The feedback loop also facilitates an error reporting system as discussed in the HF practices within the aviation industry (Hobbs, 2008).

For every step in the process, there are recommended activities which can be conducted and uncover useful information for the next step in the process. A list of these recommended activities can be found in Table 4.

Table 4.

Recommendations per proposed process phase

Recommended process step	**Recommended activities**
Throughout the process	HF workgroup, Usability champions, HF database
Analysis	Situational Awareness Analysis, Cognitive Task Analysis, Human Performance Reliability Analysis, Diagram method, Timeline diagram, Action/Information requirements, Workload analysis, Link

	analysis, Mission analysis, Design criteria checklist
Design & Development	Drawings, mock-ups, scale models, interview with user (representative), using questionnaires, secondary task monitoring
Test & Integration	Set meeting point between HFE and T&I
Aftercare	HF workgroup

The following sections explain these activities further, starting from the recommendations throughout the process, then the Analysis step, and so on to the last step of Aftercare.

2.3.1 Overall process recommendations. Next to distinguishing different phases in the renewed HF approach which the following sections will elaborate on, there are some recommendations based on commentaries from the interviewed stakeholders and their remarks concerning HF within Thales Hengelo which can be implemented throughout the process as a whole. These overall recommendations try to address the barriers identified by the comments of the stakeholders, discussed in the previous phase. First, the barrier of meeting resistance, second, little HF knowledge in other domains, third, lack of concrete usability requirements, fourth, most user feedback at the end of the design process, and finally, carrying out some HF activities in other domains.

It was noted by a stakeholder that making changes in the design which would improve certain HF aspects were initially met with resistance. Only when a manager higher on the corporate ladder got involved, the desired change was being implemented within the design. This notion of having a higher up sponsoring such changes shows overlap with the concept of usability champions as described by Mrazek and Rafeld (1992), which entails the recruitment of senior managers per discipline to act as champions, supported by an HFE. These champions are to keep an eye out for any usability related issues. Translating this to the context at hand, such champions can assume the role of sponsors as well, combining them into an HF aware sponsor which is involved in HF related activities and can bring about usability changes when necessary. Of course, individuals need to be identified who have an interest in such issues and are willing to take on a sponsoring role. If such a sponsor can be found for every involved discipline within the design process of Thales Hengelo, it may lead to less resistance to proposed HF related changes within the design at hand. As these sponsors or champions need to have some decision power, a careful approach to managers would be a good first step towards establishing such champions. However, care should be taken as this is a short-term solution for a larger problem. Having usability champions in place is a good start, however, the culture as a whole needs to change in order to accommodate acceptance of changes which benefit usability. In fact, implementing so-called "strategy usability" requires more than only a culture change; it needs to be consciously embedded in design processes, roadmaps and organizational processes (Rosenbaum, Rohn & Hurnburg, 2000). Even though high-level/founder support is a method highly effective as found by the usability experts employed in the study of Rosenbaum, Rohn and Hurnburg (2000), Mayhew (1999) makes a clear case that usability champions should aim for business support on the long term, diminishing their role on the way in doing so. This iterates the need for usability champions on the short term, which transforms to more awareness and ultimately, support from the whole business in the long term. Along with addressing and potentially overcoming the barrier of meeting with resistance, the concept of usability champions can also assist in raising awareness and knowledge of HF in other domains, contributing even further to a business change on the long term. Thus, the usage of usability champions is highly recommended.

Addressing the aforementioned remarks by the Hardware Architect and the Test & Integration manager of not knowing where HF begins and ends, a HF database could be developed in order to give these disciplines more information on what HF actually entails as well as several relevant requirements from MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019). Both such a database and the HF sponsors might bring about an increased awareness of HF within several different departments of Thales Hengelo.

In internal documentation, a template for anomalies concerning HF was found; this details several possible causes as to why an anomaly may occur. Since documentation and coordination is necessary for an integrated effort of HF (Rosenbaum, Rohn & Hurnburg, 2000), this anomaly sheet can be converted to an Excel spreadsheet in order to keep track of any HF anomalies and their causes. This spreadsheet can be used through all steps of the design process and could possibly provide rich information to be used in other comparable product designs as well. The HFE can use this to create a comprehensive database, so that the same problem does not need to be solved twice when encountered due to a lack of documentation. Furthermore, this makes it easier to gather input from other stakeholders, for example, by setting up a HF workgroup and discussing the issues recorded in the document. Members of the HF workgroup can also access the document and add HF issues from their domains as well. This raises HF awareness and knowledge, as well as gathering a more coordinated overview of other HF activities in domains, since these can be brought up during the HF workgroup meetings and can be noted down on the HF anomaly sheet. Thus, it is recommended setting up such a HF workgroup as well.

Summarizing, the overall process recommendations consist of employing usability champions, setting up a HF workgroup and a HF database, and using the HF anomaly sheet. In the sections below, the different phases in the proposed HF approach are outlined further. These are based on MIL-HDBK-46855A (US Department of Defense, 1999), which distinguishes three phases to HF integration and overall process, being Analysis, Design & Development, and Test

& Integration. Added to this is the phase Aftercare; as noted by the Customer Care Engineer, staff at the end of the design process and who maintain contact with the customers receive more feedback on the product. These stakeholders are Test & Integration, Trainers, and the Customer Care Engineers. If only the three phases as proposed by MIL-HDBK-46855A (US Department of Defense, 1999), would be implemented, personnel receiving such valuable customer feedback are disregarded and not a part of the process. The phase Aftercare collects this feedback so that it incorporates staff directly in contact with the customer, which can be used for future, comparable products or product components. By doing so, the proposed process bears resemblance to the processes proposed by Karsh, Holden, Alper and Or (2006) and Money, Barnett, Kujis, Craven, Martin and Young (2011) in medical engineering literature, where emphasis was also placed on collecting user requirements, and connecting phases by means of a feedback loop.

A final note regarding the phases is the usage of methods. MIL-HDBK-46855A (US Department of Defense, 1999) outlines several methods for each phase, however, it is not advised to execute all these methods as some are quite overlapping. In addition, some of the methods are not applicable to all projects but can be useful to some specific ones. Therefore, it is proposed to have a base set of methods per phase, performed for every project. If necessary and applicable, additional methods can be selected to derive further information. This addresses the concern that a one-size-fits-all approach is not desired. As the barriers of having user feedback at the end of the design process and of not having concrete usability requirements have not been addressed yet, these will be addressed by the recommendations during the Analysis phase.

2.3.2 Analysis. The first activity, or step, should be an analysis which has as main goal to gather information to feed into requirements. This ensures that HF considerations are incorporated into the design as well as possible as recommended by MIL-HDBK-46855A (US Department of

Defense, 1999) and addresses a concern apparent in the current process: Thales Hengelo knows how to design, but not what to design. Users, or user representatives, should be involved in order to derive user requirements, feeding into the SSS/requirements phase of the design process of Thales Hengelo. This is not without issues; amongst others, care should be taken to translate these user requirements to applications within the design meaning that what the user wants is not necessarily what the user needs (Elm et al., 2008). Thus, the HFE should take care to translate these user wants to user needs and use that as a starting point for viable requirements. A list of viable requirements based on the aforementioned translation should be considered as the output of this process step and corresponds to the SSS/Requirements phase of the design process at Thales Hengelo. These requirements further ensure the involvement of users, or user representatives earlier in the design process, and can be formed into concrete usability requirements.

Several HF methods exist in order to arrive at such a requirements list. MIL-HDBK-46855A (US Department of Defense, 1999) outlines 16 HF methods, most of which are applicable during the analysis phase. Highly recommended is the use of a cognitive HF method, since the used MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019) barely addresses cognitive considerations. As proposed by MIL-HDBK-46855A (US Department of Defense, 1999), the cognitive methods consist of a cognitive task analysis, human performance reliability analysis (HPRA), and a situational awareness analysis. Furthermore, a diagram method for tasks such as a functional flow diagram, flow process chart, decision/action diagram or operational sequence diagram may be of assistance in deriving user requirements, as well as both physical and cognitive HF considerations (MIL-HDBK-46855A, US Department of Defense, 1999). If a diagram method is selected and employed, timelines and action/information requirements can be derived from the diagram as well. Other methods which could be of value within the context at hand are workload analysis, link analysis, mission analysis and the usage of computer aids. The methods will be briefly explained, starting with cognitive methods, moving on to diagram methods, and finally conclude with other methods which do not fall in one of the categories.

The cognitive task analysis is a method which focuses on the mental representation of an operator, and the knowledge and skills required to perform tasks, and can be used to explore how cognitive processes of the user are formed during the performance of a task (Dismukes, 2010). MIL-HDBK-46855A (US Department of Defense, 1999) notes that the cognitive task analysis is especially useful when a task is not performed very often, as is the case with most maintenance activities in the products of Thales Hengelo.

Human Performance Reliability Analysis (HPRA) is an analysis which has the main goal of determining the factors which are needed for a person to reliably perform within a system or a process.

The last cognitive method as proposed by MIL-HDBK-46855A (US Department of Defense, 1999) is the situational awareness (SA) analysis, which has been defined by Endsley (1995) as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (p. 36). This may provide insights into differences between novice and expert users, as abilities for assessing the status on different levels may become apparent.

The diagram methods as proposed by MIL-HDBK-46855A (US Department of Defense, 1999) are largely similar to one another. The Functional Flow diagram provides a detailed inventory of system requirements when finished and could possibly serve as an input for the previous discussed cognitive methods. The operational sequence diagram is more detailed than the functional flow diagram and allocates functions to either human or system. The flow process chart makes more use of symbols and is more detailed than the functional flow diagram. Finally, the decision/action diagram focuses on the decisions taken. If a diagram method is used, the diagram could be expanded by using action/information requirements, detailing the specific actions and specific information needed to perform a task, as well as using timelines, which specifies the time needed to complete a task.

Other methods which do not fall in the cognitive or diagram category include the mission analysis, which focuses on defining what tasks the total system must be able to perform. Furthermore, there is the usage of computer aided tools, link analysis which maps the needed interactions between components within a system and revealing bottlenecks in task execution, and workload analysis, which could be integrated within a cognitive method mentioned earlier.

2.3.3 Design & Development. With the requirements from the Analysis phase as input, the Design & Development phase has as its goal to check whether there is compliance with the requirements and to provide recommendations. If deemed necessary, this phase can also require design changes to address possible non-compliance. This phase can be seen as a continuation of the Analysis phase and their methods; however, whereas the Analysis phase focuses on requirements in a stage where not that many details are known, the Design & Development phase focuses on a stage where details of the design become increasingly more coherent and clear. Methods accompanying this phase are using a design criteria checklist, drawings, mock-ups, scale models, test participant history record, interviews, questionnaires, and secondary task monitoring. The design criteria checklist derives from the Analysis step, where criteria have been derived and the design can be checked using a checklist detailing these criteria. Drawings, be it virtual or on paper, can be used to assess whether the design is compliant to the set requirements.

Mock-ups are constructions built to show the design and can be used to assess aspects such as size to benefit usability. Scale models can be used for a 3D-representation of the design. These methods are intended to make the design more visual, which can then be tested with users or user representatives. Test participant history record can be uncovered as to see what the user or user representative level of experience is, and check whether users or user representatives with a lower or higher experience level can conduct the same tasks as fluently. Interviews and questionnaires can be conducted among the users or user representatives after the user testing to reveal bottlenecks which may not have been obvious to the HFE during the user test. Finally, secondary task monitoring is a method of measuring mental workload by having the participant executing two tasks at the same time. This is especially useful when in the Analysis phase a workload analysis has been done and doubts are present.

Altogether, continuation of the methods selected in the Analysis phase is also recommended here. This is in order to check whether the outcomes of the Analysis methods are still in line with what is found during the Design & Development phase, or whether rectification is deemed necessary. The methods are dependent on the level of design; if it is still somewhat abstract and concrete, user testing through scale models which can be easily adapted is preferred; if the design is already on a detailed level, mock-ups are preferred. Thus, the selection of methods is dependent on the level of detail of the design at hand and should therefore consist of at least one method suitable for a low detailed design and one method for a high-level detailed design to ensure compliance to requirements on both a detailed and abstract level. A consideration which needs to be made here is to distinguish how often a maintenance task as identified in the Analysis phase needs to be done, and what details need to be remembered. Testing methods, as proposed in the beginning of this section, can answer this question and provide information on HF aspects of the design at hand. The Design & Development phase is parallel to a few steps within the design process of Thales Hengelo; it starts at System Engineering and ends at the final CDR. Since the methods are dependent on the level of design, recommendations are tough to provide at a stage where no design is present yet.

This phase contains two reflective moments embedded in the design process, that of the PDR and CDR. Before the PDR, the HFE should have a finalized list of usability requirements and their level of compliance, assessed through testing. Dependent on resource constraints, any potential redesigns should be tested between the PDR and CDR to ensure that redesigns which benefit usability are actually capable of doing so. If this is not feasible, users or user representatives should at least be able to comment on redesigns aimed at improving usability, and preferably, on all proposed changes to the design.

2.3.4 Test & Integration. MIL-HDBK-46855A (US Department of Defense, 1999) proposes as the last phase a Test & Evaluation phase, where compliance to requirements is being tested and evaluated. As can be seen in the current process of Thales Hengelo, the Test & Integration department is already carrying out requirement testing. Therefore, instead of carrying out methods associated with this phase, a set meeting point is being proposed to discuss HF related issues. Aside from gaining feedback, this serves as a method to raise awareness on HF across various departments of Thales Hengelo as noted in the previous overall recommendations section. This can be done by having a manager of Test & Integration as a member of the earlier proposed HF workgroup, and filling out the earlier discussed anomaly sheet.

It should be noted that the Test & Integration department does not prove compliance to the earlier set HF requirements; this is done through analysis from the HFE, which delivers the needed proof of compliance. Thus, HF issues uncovered by activities of the Test & Integration which are not addressed yet in the provided HF requirement compliance sheet should be reported back to the HFE.

2.3.5 Aftercare. The final phase is the Aftercare and starts when the product is about to be delivered to the customer. Customer Care Engineers maintain a quite high contact level with the customers, making feedback from actual users rather than user representatives most apparent. Staff of Thales Hengelo which is in contact with most of these users can collect HF-related feedback and relay them back to the HFE. This can be done by establishing the earlier mentioned HF workgroup, who come together at a yet to be determined frequency and discuss all usability issues and other HF-related feedback as heard from the customers. Other than feedback, this workgroup can also discuss ongoing internal HF processes, future HF directions, best practices in design, managing the overall HF process and spreading awareness and knowledge within Thales Hengelo. Doing so fulfills the goal set for this phase, being an assessment of the design based on customer feedback from a HF perspective. The output of this workgroup should be a list of considerations to be taken into account when designing future, comparable products, which can serve as an input for the Analysis phase of such a product.

2.4 Discussion

2.4.1 The current process. A point which is becoming immediately evident within the current process of Thales Hengelo is the non-focus on usability. This is not to say that usability is not being considered at all; however, it is rather low on the priority list. This is evident from the use of MIL-1472-G_CHG-1 (US Department of Defense, 2016), which focuses on physical aspects but neglects usability aspects and cognitive considerations. These usability aspects and cognitive considerations are not addressed in other parts of the current HF process at Thales Hengelo. Furthermore, when a product redesign has been realized, this redesign is not being tested again.

Thales Hengelo is thus at the moment mitigating risk non-compliance, rather than designing for usability. This is troubling, since the relationship between risk and usability as discussed in the first phase of this report is thus being disregarded. This might explain the experienced gap between theory and practice as commented by a stakeholder, since the requirements from the MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019) are largely theoretical and do not consider specific contexts surrounding the user. The disregard for user contexts does not support the achievement of optimal usability and thus reducing the potential for error is not taking place from such perspective. Furthermore, this is not in line with the call for looking at maintenance activities within an organizational, cognitive and physical context as has been made by Sheikhalishahi, Pintelon and Azadeh (2016). Only the physical context is being considered by the MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019). Cognitive aspects might be considered as an underlying factor within the standard; however, these are not apparent and clear as such and gives no handle for the HFE to assess cognitive considerations in a practical and concrete way.

The only structured HF activity in this process is the usage of the aforementioned MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019) checklist, which influences the stages of SSS/requirements, System Engineering and Mechanical Electrical/TU-RF, as well as the PDR and CDR.

A few further notations regarding the MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019) are in order here. The reader may note that the standard is not as recent as may be desired in academic literature as its first version was published in 1968; this might have consequences for the applicability of the standard. Furthermore, as the military standard is developed by the US, the question arises whether this standard can be used in other, non-

American cultures as well.

Regarding the first notation, the MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019) has been revised over the years, evolving along with certain technical developments. Additionally, a case is made by McDaniel (1996) that it cannot be expected from a military standard to follow along with the rapidly evolving technology in for example the electronics industry, whilst remaining effective and efficient. Even though technology is changing rapidly the last few decades, the human body has not. The standard describes design requirements based on the physical strengths and limitations of humans, and thus the standard is still applicable and will be for the foreseeable future. Finally, the MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019) focuses on HF aspects of the Defense Industry which other standards do not address. Since Thales Hengelo operates within the Defense industry, compliance to a military HF standard is of utmost importance.

Cross-cultural differences are acknowledged in MIL-HDBK-46855A (US Department of Defense, 1999), stating that cultural differences which might influence the perception of the military design might be resolved through adapted training programs, tailored to the specific audience. For example, cross-cultural differences may even contradict each other in terms of reading direction (e.g., from right to left as opposed to left to right). Whilst an argument can be made from the HF perspective that training is an expensive solution and that the design should be ready to catch such cross-cultural differences, this might not always be possible. Consider product companies such as Thales Hengelo, who sometimes do not know the customer beforehand. Accounting for each and every cultural difference that may exist which could interfere with operating and maintaining their products might not be possible or feasible.

Therefore, the adherence to the MIL-STD-1472-G_CHG-1 (US Department of Defense, 2012) is an element which should be kept in the HF process at Thales Hengelo. However, caution is needed to not see this MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019) of sufficiently addressing every and all HF aspects present in their products. Even though the MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019) addresses the physical capabilities and limitations of humans, little to no attention is given to human cognition. Thus, the need for other methods which address human capabilities and limitations not considered by the military standard is apparent. Organizational and cognitive aspects should not be ignored, since these can lead to errors and accidents as a result of their interactions (Sheikhalishahi, Pintelon & Azadeh 2016). Some of such methods are listed in MIL-HDBK-46855A (US Department of Defense, 1999), which complement the MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019). Additionally, other standards for usability can be checked. Although customers of Thales Hengelo do not require compliance to other standards than the MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019), such other standards could still be used to improve usability. An example of this is the aforementioned document of the American FDA within the medical device context. Some of its guidelines may not be applicable to the designs that Thales Hengelo produces, such as the interface guidelines, which are not applicable for hardware components. However, most guidelines are common enough so that it can be used within the context of Thales Hengelo as well. ISO standards can be searched for as well to determine applicability; ISO standard 6385:2016 (2016) focuses on ergonomics in various work systems. Thus, apart from MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019), the search for other, applicable standards which focus more on usability and ergonomics should continue.

The need for additional methods has become clear as well to address the gap between theory and practice. It is clear that Thales Hengelo knows how to design systems; however, this gap indicates that Thales Hengelo does not necessarily know what to design in order to accommodate end-users. The iterative feedback loops within the regular design process are of great value to reflect on the requirements and the final design. As the review during the PDR and CDR is a reflective moment, there is some feedback there, however, there is little involvement from HF in design phases after that. Gathering feedback from user representatives on the final design can be valuable in order to learn and gain knowledge and experience for future, comparable products. Additionally, when it comes to requirements, these are discussed with the client (if a launching customer is involved), but not with an actual user or user representative from the launching customer's side. Thus, actual user feedback is only present when the product has gone through all cycles of the design process, when the HFE is no longer involved and when changes can no longer be made to the overall design. This is not to say that such user feedback is not valuable anymore; rather, this user feedback should be collected in order to learn and apply it to future, comparable products. These observations point to a need for information collecting, preferably early in the design process in order to consider the various user contexts and what is needed in the design to support maintainers in their activities. This enhances the usability as well, since user feedback usually considers the user context (Scholtz, 2004), thereby reducing the risk of errors occurring in real-life conditions.

2.4.2 Identified barriers. The five identified themes, or barriers, bear resemblance to the earlier presented framework of Waterson and Kolose (2010). The first theme, being that there is little knowledge and awareness of HF, resembles the barrier within the framework of HF data being different. Engineers who expect that HF data is similar to theirs might have this expectation due to sparse knowledge on what HF actually entails.

The second theme identified within Thales Hengelo is that of usability requirements not being considered or set. The focus on usability, as has been noted when discussing the current process, is rather low. This was to be expected, as the Defense Industry sees HF as a means towards reducing risks, and not so much as a tool to improve usability (Stark & Kokini, 2010).

The third theme is that of user feedback at the end. This is not surprising to find as a barrier, as no users are involved in the earlier stages of the design process of Thales Hengelo. Karsh, Holden, Alper and Or (2006) noted this as well within the medical engineering field, and tried to pull the user feedback more forward in the process by initiating a feedback loop and deriving user requirements early on in the design process. As the recommendations given follow this model as well, the barrier of usability requirements is therefore mitigated.

Fourth, the theme of resistance to changes was found. Specifically, when a change aimed at improving usability is proposed, there is resistance due to it costing too much to change the product, or because the benefits do not weigh up against the effort to implementing that change. This relates to upper management not seeing the value of HF, as has been pointed out by the framework of Waterson and Kolose (2010) already. Upper management does not see the value of HF or usability and is therefore at the least hesitant unless there is hard evidence that a usability change can bring about benefits. The recommendation of usability champions aims to raise the awareness of upper management on the type of benefits that HF and improved usability can deliver, whilst lowering the resistance. On the long term, a culture change is necessary. The recommendation of usability champions is therefore seen as a tool to cause such change in the long run.

Lastly, there is the identified theme of carrying out HF activities in other domains. This might be due to there being only one member of the HF team within Thales Hengelo. Relating this to the framework of Waterson and Kolose (2010), the degree towards which the HF team collaborates with other departments might be the cause of this identified theme. As there is only one HFE within Thales Hengelo, it is not surprising that the collaboration is on a lower priority, due to having a lot of other HF-related duties to carry out. The recommendation of the HF workgroup can therefore strengthen this degree of collaboration, mitigating the identified barrier.

All in all, the barriers found within Thales Hengelo are not surprising as they all relate to aforementioned findings within HF literature as presented in the first phase of this report. The recommendations given are aimed specifically at mitigating these barriers.

2.4.3 Recommendations. The given recommendations in this report are built on the foundation of MIL-HDBK-46855A (US Department of Defense, 1999) and the comments made by the interviewed stakeholders. As MIL-HDBK-46855A (US Department of Defense, 1999) complements the used MIL-STD-1472-G_CHG-1 (US Department of Defense, 2019), the methods will not clash with the set requirements and can be used to check compliance within the standard. However, some of the methods and the recommendations can be replaced by one another. For example, if a situational awareness analysis is being done, a full conduction of another cognitive method might not be feasible as this might yield a lot of similar data. The range of different projects within Thales Hengelo, however, calls for flexibility regarding the used methods. Whereas situational awareness analysis might be applicable for one project, it might not be applicable for another project which takes place in another context. Therefore, the range of recommended methods can be seen as more applicable here. This is further iterated by Vredenburg (2002), who noted that a one-size-fits-all approach is not feasible.

Adding the phase of Aftercare to the process indicates that other barriers are mitigated as well, since MIL-HDBK-46855A (US Department of Defense, 1999) does not suggest such a phase to the HF process. Therefore, the recommendations given are based on both literature and the identified barriers, making them applicable within the context of Thales Hengelo. However, this can be substantiated further by having stakeholders judge the given recommendations. This will be done in the next phase of the report.

3. Phase 3: reaching consensus

The list of recommendations generated in the previous phase needs to be assessed according to the set requirements of Thales Hengelo. These requirements were that the recommendations are applicable, effective and future proof. Stakeholders are therefore asked to evaluate these recommendations based on these criteria. The evaluations are gained via certain methods, which will be explained in the first section of this phase. Then, the results are presented. The final section contains a discussion on the research as a whole and provides a conclusion as well.

3.1. Method

In order to gain a consensus overview, the Delphi method (Dalkey & Helmer, 1963) can be used. The Delphi method focuses on attaining consensus among experts, and consists of multiple rounds, gathering feedback from individuals through questionnaires or interviews. In this study, the Delphi method is used but adapted it slightly, as sometimes, cooperation between departments is needed. The Delphi method holds that stakeholders should be asked for feedback in an individual setting, which some methods here do, but not all. Meetings with these departments to reach consensus over the cooperation and its goals was therefore necessary. Consensus was obtained with three rounds, explained in the next sections.

3.1.1 Offline questionnaire. This round focuses on an initial perspective of the given recommendations. The round serves to discard any recommendations which are deemed not applicable on a face-value according to the stakeholders.

The recommendations were summarized in a PowerPoint presentation, providing an explanation of them in the notes per slide, and were emailed to all previously interviewed stakeholders, plus one other interested colleague, not earlier identified. The total number of participants for this method were thus nine, and all had again different roles within Thales Hengelo. These are Test & Integration Manager, System Engineering Manager, Safety Engineer, Documentation Author, Customer Care Engineer, Logistic Engineer, Computer Security Specialist, Hardware Architect, and a Maintenance Intelligence Engineer. Characteristics of the participants other than their role are not known to the researcher due to corporate confidentiality reasons.

Along with the presentation, a set of questions aimed at gathering qualitative answers was sent along. The questions were aimed at gathering the opinions of the different phases within the proposed HF process and evaluating the proposed methods. The goal is to determine the applicability and perceived effectiveness of the proposed process and serves thereby as a possible ground to change some of the recommendations. The questions asked can be found in Appendix C. Answers were collected via email, and then put in a Word document, separated per stakeholder. Five responses were received, achieving a response rate of 55,5%.

3.1.2 Structured interviews. A structured interview with the user representatives, being a trainer and the Test & Integration manager, as well as the HFE, was set up in order to have a final evaluation on the proposed process from their perspectives. Other, not yet unrevealed information such as causes of errors made by maintainers were also asked there. The full list of questions asked during the interview can be found in Appendix D. The interview lasted an hour and thirty minutes and was conducted in Dutch over a telephone conference. Some of the questions could not be asked during the interview itself due to time constraints, however, answers to these were later obtained via email. This method focused on assessing the perceived long-term potential of the proposed process, as well as judging the effectiveness and applicability. Answers were collected via note taking and email correspondence.

3.1.3 Online survey. A survey was constructed where respondents were asked for their line of work and could judge the usefulness per recommendation for their job. This allows for differentiation between the different involved domains, as some recommendations given may be more useful for specific domains than it does for others. Questions consisted of an explanation of the recommendations, and respondents could indicate on a 7-point Likert scale how useful said recommendation would be within the context of their job. For some recommendations which can be replaced by alternatives, preferences could be indicated as well. The full list of questions can be found in Appendix E. The survey was sent out to earlier identified stakeholders, and some of their colleagues, ensuring that at least two individuals of a specified domain had been sent the survey. The survey was sent to the earlier pool of participants, with additional colleagues working in the same domains already mentioned. The total number of the respondent pool were 17 employees. Respondents were approached via email containing a link to the survey and an explanation. Nine responses were obtained, achieving a response rate of approximately 53%.

3.1.4 Data analysis. The qualitative data gathered from the offline questionnaire were analyzed by reading them through carefully and sorting them according to similarity. Similar sentiments were grouped together. Comments relating to the same sentiment were counted by hand. This resulted in a content analysis. Answers are reported on the level of agreement and how many respondents out of the total indicated their agreement.

For the structured interview, answers were summarized. Answers from the participants which were similar were grouped and reported together. This resulted in an overview of agreement, which is reported in a summarized form of the answers of the participants.

As for the online survey, the software of Qualtrics was used for data collection. The median and the IQR were calculated for each question. These are indicative of the agreement on every statement and follows the method as employed by a paper by Polisena et al. (2018), were consensus was reached by means of a similar survey. Nine responses were collected, of which three were incomplete. These three have still been included within the data set, as most of these responses came from the Specialty Engineering domain. As Specialty Engineering has been represented in three of the complete responses already, this indicates that there is already good enough representation of the domain, and that their answers would not skew the statistics too much.

As some of the respondents were the only ones in their domain, it might not be beneficial to conduct an analysis as to which recommendations are the most useful for their domains, since this would be not a representative overview of the HF needs for the domain. Thus, the focus is on an aggregated overview where no distinction between all the different domains has been made. As the Specialty Engineering domain is heavily represented, differences in their aggregated responses and the total responses are reported.

3.2 Results

3.2.1 Offline questionnaire. The main findings of this method are summarized in Table 5.

Table 5.

Main findings of the offline questionnaire

Recommendation	Consensus
Usability champions	Good idea; but see it as a means toward improved HF awareness
Number of phases in the proposed process	Sufficient in this way
Cognitive methods	Useful to execute; most applicable is situational awareness analysis
Diagram methods	Torn between operational sequence, flow-process chart and Decision/Action diagram
Judge per project which method is most applicable	Emphasized by others as well, a good argument needs to be made

When asking stakeholders on the notion of using usability champions through the offline questionnaire, this was met with enthusiasm. All respondents agreed that this is a good idea, however, one of them warned that it should not be the long-term goal, rather a means towards raising HF awareness within various disciplines. Therefore, this recommendation is adapted to see it as a means towards an improved awareness of HF.

The respondents to the questionnaire all noted that the number of phases was sufficient in the proposed way, however, maybe a name change could be done for the Analysis phase by renaming it Define phase, where requirements are being made. As this was noted by only one respondent, this name changing is refrained from. On being asked whether the Aftercare phase and the T & I phase should be combined during the questionnaire, the answer is a largely consensual “no”, where most stakeholders (n = 4) agree that these are distinctly different phases. One respondent said that they could be combined, however, as the consensus lies with the phases remaining different, this will be kept in the same way.

As a comment, one of the questionnaire respondents noted that when usability requirements would be recorded, these should be considered within the working process. This can be done through a process description, a template, or for example a list of requirements.

Therefore, setting up a list of requirements from the Analysis phase ensures that HF is considered within the design process.

The respondents noted in their questionnaire answers that the cognitive methods would be useful to execute, as there is of yet little attention towards cognitive aspects. The method judged the most applicable is the situational awareness analysis, as three of the respondents thought it would be valuable. However, the cognitive task analysis would be useful for different systems and could be applied to a wide range of projects according to another respondent: “describing the skills and knowledge needed could be helpful when designing our system, so that users with less cognitive skills are able to use it as well as users with more expertise”. As for situational awareness analysis, a respondent noted that “what is needed in terms of knowledge and skills is useful when thinking about our design, what we can do in our design to accommodate users with their situational awareness”, and “as our customers have different backgrounds, something needs to take that into account”. However, care should be taken: “be careful with situational awareness; have a very good idea what that entails, both from a literature perspective and the perspective from Thales.”

The respondents were torn judging which of the diagram methods are the most applicable. Operational sequence is mentioned by two respondents, the flow-process chart is mentioned by one, and the Decision/Action diagram is mentioned by another. Thus, most preferences went toward the operational sequence diagram. As for the additional methods such as a timeline to be used when a diagram method is used, most respondents (n = 3) saw the value of that as well.

Three respondents agreed on only applying a method such as link analysis, workload analysis and computer aided tools when more analysis and information is needed. This implies to incidentally carry out these activities when the situation calls for it as opposed to carrying it out for every project.

The HFE noted that it should be examined per project which method is best applicable. Sometimes, outputs from methods could be used in other projects as well, since some of the data may be the same. Other comments (n = 2) emphasized this as well, saying that a good argument needs to be made when to use which method. As this is dependent on the context of the project, there will be no determination here which method is best applicable for what project; this is also beyond the scope of this research.

Further recommendations as given by the respondents in the questionnaire might be using simulations to enact different scenarios and see how users or user representatives act on these.

3.2.2 Structured interviews. The main findings of this method are summarized in Table 6.

Table 6.

Main findings of the structured interviews

Question	Answer from the participants
Process sufficient in this way?	More set contact points early on in the process
Gap between theory and practice mitigated?	Dependent on the level of representation
Room for sufficient user feedback?	Visual aids may help
HF awareness within the departments?	Already maximum, but meeting points may help with bringing awareness to young and new employees

Most recommendations given by the trainer complement the proposed process. In their view, the process will gain benefit with three more set contact points between the HFE and the user representatives. These three contact points are around the PDR phase, being 1) when clear models of the design at hand are available, 2) the first setting to work, when T & I is testing the product for the first time, and 3) the aftercare phase, where frequent meetings between trainers, customer and T & I is desired. These meetings during the aftercare should last years into the future as well, since it is expected that the customer will gain a different experience after a few years of working with and maintaining the product. This is substantiated by the theory of usability and its learning effect; specifically, the crossover point as developed by MacKenzie and Zhang (1999). Even though there might be no comparable product within reach of the customer, the crossover point model still holds that performance increases over time. With this increased understanding, there might also be new insights into the usability of the design which are not apparent in the first few uses of the product, as is the case during the training course at Thales Hengelo. Therefore, aftercare in the form of meetings several years after the product is in use at the customer is of importance to uncover these new insights on usability. The trainer foresees the proposed process working on the long term as well when these three contact points are being set every time the process is being used. However, the HFE notes that closing the gap between theory and practice in this way is dependent on the level of representation of the user; that is, how well can the trainers and T & I staff represent the users during meetings where no actual user can be present. Feedback from the Aftercare phase could be used in order to estimate how large this difference between user representatives and actual users is.

On the question whether there is room for sufficient user feedback in the proposed process, the trainer noted that it might be difficult, and visual aids such as 3D-models and the usage of VR might help to uncover potential maintenance problems. However, the barrier identified here is that of resources, being finances and capacity. Concrete user requirements as per the Analysis phase can be illustrated with both good and bad examples of comparable, earlier products to explain the foreseen problems further. Involving the customer, by for example setting up a cooperating training effort, could be of further assistance. Finally, the trainer recommended to evaluate this proposed process on earlier finished processes or already finished processes. The HFE expects that there will be enough room to consider user requirements with the proposed set meeting points as given by the trainer. As for the concreteness of the user requirements, this is dependent on the level of detail of the design at that point, and how clear the role of the user is at the moment. This is a dependence which lies outside of the control of the HFE. All in all, the HFE does expect that the process will assist at improving usability. They foresee that as more flaws in the design can be prevented, the Analysis phase supports more logical design choices from a user perspective, and the Test & Integration and Aftercare phase can reveal more future usability shortcomings in the design.

Regarding the barrier of HF awareness and knowledge, the trainer commented that the HF awareness within the trainer department is already at a maximum; however, when this proposed process enhances the chance for improving HF implementation this is beneficial as well. The T & I manager noted that some of the new employees within his department are not fully aware of HF, and that it might be useful to invite the HFE once per month to a weekly meeting to raise this awareness. This can also be used to report any HF-related issues found by the T & I employees to the HFE. On the other hand, the HFE can invite T & I employees and trainers to the PDR as well and make a case when a HF issue has been found. In this way, there is an interaction where the HFE pulls the trainer and the T & I earlier in the design process, and the T & I and trainer involves the HFE at the end of the process more.

Most mistakes from maintainers in both preventive and corrective maintenance lies in not following the documented procedures, as according to the trainer. This might be due to experience. Furthermore, the trainer also notes that there are some flaws in the design. Involving someone from the documentation domain in the earlier proposed HF workgroup could mitigate this issue.

A last, interesting comment by the trainer was that there is a shift within the maintenance aspect of the products; there is less and less hardware, and maintainers are being trained to use a software which directs the maintainers to an error and gives a status overview. The trainer noted that there is little HF attention towards the maintenance software as of now. This is therefore an aspect on the long term which needs to be addressed as well to ensure the proposed process remains future proof. The HFE does expect that the process remains future proof as well, since some outcomes of the Analysis phase can be applied to future comparable systems as well.

Finally, the HFE notes that there should be a good, thorough look on how to implement this process in practice, considering budgets and resources of Thales Hengelo.

3.2.3 Online survey. The original goal was to differentiate between domains as to what recommendations are the most applicable per domain. However, as some of the respondents were the only ones in their domain, this is not feasible since this would not be a representative overview of the HF needs for the domain. For Specialty Engineering respondents only, the recommendations which were found the most useful were the set meeting point between the HFE and T&I (Mdn = 7) and the diagram method (Mdn = 7). The least useful recommendation was that of the timeline diagram, secondary task monitoring and the workload analysis, which all had a median of 3.

The median and the inter-quartile range (IQR) per scale question for all respondents can be found in Table 7. Additionally, a decision is made according to the Median and the IQR as to whether the recommendation is deemed relevant or not. Recommendations which received a median lower than 3,50, the midpoint, will not be kept in the final list of recommendations.

Table 7.

Results of the online survey

Recommendation	**Median**	**IQR**	**Recommendation kept?**
HF workgroup	6	0	Yes
Usability champions	5,50	1	Yes
HF database	6	3	Yes
Situational Awareness analysis	6	0,75	Yes
Cognitive task analysis	5	2	Yes
Human Performance Reliability Analysis	5	3	Yes
Diagram method	6,50	1,75	Yes
Timeline diagram	3,50	1,75	Yes
Action/information requirements	6	2	Yes
Workload analysis	2,50	1,75	No
Link analysis	5,50	1,75	Yes
Mission analysis	6	0,75	Yes
Design criteria checklist	5,50	1	Yes
Drawings	5	2	Yes
Mock-ups	6	0	Yes
Scale models	6	0,75	Yes
Interview with user (representative)	5,50	1,75	Yes
Using questionnaires	4	1	Yes
Secondary task monitoring	2,50	1	No
Set meeting point between HFE and T&I	6,50	4	Yes

Note: Answers were given via a 7-point Likert scale, where 1 was set as not useful at all, and 7 as very useful.

As the maximum score of 7 indicates that the recommendation is useful and 1 not useful at all, on average, the recommendations have been found useful. Only the recommendations of workload analysis and the timeline diagram fall below the midpoint of usefulness. The most useful recommendation is that of the diagram method, as its median is 6,50. The set meeting point between HFE and T&I has the same median, however, the IQR differs widely. The set meeting point has an IQR of 4, which might point to the fact that it is useful for only some domains and not all who responded to the survey. On the other hand, the IQR for the diagram method is 1,75, which can be deemed as acceptable. The lowest IQR is found for the recommendation of the HF workgroup, which accompanies the median of 6, and the recommendation of using mock-ups, which also has a median of 6. This indicates that both the HF workgroup and the usage of mock-ups are useful across the domains of the respondents of the survey.

As for indicating preference, three respondents preferred the Situational Awareness Analysis, and two respondents preferred the Human Performance Reliability Analysis. One of the latter indicated that the Human Performance Reliability Analysis could be conducted first, followed by a situational awareness analysis. The other respondents did not indicate a preference here. This is remarkable, as during the offline questionnaire, respondents did not comment on the Human Performance Reliability Analysis. For the diagram method, two respondents chose the operational sequence diagram, and the other methods were preferred by one respondent each.

3.3 Overall Discussion

After reaching for consensus by means of an offline questionnaire, structured interviews with user representatives and the HFE, and an online survey, consensus and agreement has been indicated by several different stakeholders from different domains. These answers revealed whether the proposed recommendations and process are indeed applicable, effective and future proof. This section will detail this further by discussing the limitations of this research, as well as directions of future research and closes with a final conclusion.

3.3.1 Limitations. The biggest limitation of this research is that the validity cannot be assessed as of yet. This can only be done through testing the recommendations in a real-life setting and collecting evaluations thereafter. However, as this research aimed first for providing feasible recommendations, one can hold that this is not a limitation, rather a start-point for future research.

Secondly, the methods and recommendations are derived from literature. It is not yet very clear how these methods and recommendations could be shaped to fit the context of Thales Hengelo better, although some advice has already been given by stakeholders. Only by testing these recommendations and methods in practice could a full image on how to conduct the proposed process in its whole form be revealed. Again, this can be resolved by carrying out a future research aimed at bringing the process into practice.

The generalizability of this study is rather low. However, as this study was aimed to provide recommendations specifically for Thales Hengelo, it was not intended to act as a generalized research on HF integration into companies. This is not to say that this research is without use for other practitioners wishing to integrate HF. Our methodology to consider various stakeholders and the context can be used for comparable research.

Another limitation is the presence of only a single HFE within Thales Hengelo. This is not necessarily a substantial problem as such; however, it may have shaped the opinions of the HFE and the direction in which the recommendations have taken. Additionally, only one member of every discipline participated in the interviews. Whilst care was taken to interview individuals with at least a few years of working experience of Thales Hengelo, the interviews might not give a complete overview of the HF needs and views of the discipline as a whole. However, this selection of views provided a nuanced overview already, considering the number of recommendations needed to cover barriers. Furthermore, the fact that some of the barriers were mentioned multiple times by different disciplines reveals that there is consensus between different disciplines on what aspects of HF within Thales Hengelo needs to be addressed and what is needed. This gives more support to the assumption that most barriers and wishes have been identified. Additionally, the survey attempting to reach consensus was sent to at least two employees per domain. Although there were only multiple responses for the Specialty Engineering domain, the survey revealed a high level of consensus for most recommendations.

Although the recommendations have been explained to the participants in the methods, chances still are that the participants did not have a full understanding of the proposed recommendations. Most participants work in other fields than HF engineering, so they may not be familiar with the recommendations mentioned. However, most of the comments during the offline questionnaire revealed at least some understanding of some the stated recommendations. As the participant pool largely consisted of the same people, it can be assumed that there was at least a basic level of understanding there. Furthermore, this can be addressed through future research where the recommendations are executed so that participants can see what the recommendations fully entail.

Finally, when proposing this process, constraints such as budget and resources have not been considered. However, most methods inherent to the phases can be carried out relatively cheap, except for the hours of work put into them. There is enough room to handle these methods in a flexible manner, allowing them to be executed in relatively little time and to mold them into the constraints set by budget and resources. Another way to overcome this limitation is for Thales to explore a potential cost-benefit analysis, such as to convince upper management to free up resources and budget to allow HF techniques to be used in a more detailed and thorough manner. Karat (1990) employed two usability studies in her cost-benefit analysis, where several advantages were found, saving costs and gaining more benefits for a design which was developed along with HF recommendations and HFEs. This finding could possibly be replicated within Thales Hengelo as well.

3.3.2 Future research. In order to give a more substantiated and nuanced answer on the research goal, the effectiveness of the proposed process can be evaluated by means of testing the process. This can be done by setting up a sub-case per phase and testing it according to the methods as described in this report. This will either create a more strengthened argument in favor of this process or call for adaptations to the made recommendations. Alternatively, future research can also focus on determining which method is the most applicable, differentiating between different kinds of projects and the level of detail necessary for every method. Furthermore, the HF database can be expanded upon, determining the exact needs and developing the database itself, and afterwards assessing its effectiveness.

Outside of Thales Hengelo, this research may provide a framework for first starting out to identify needs and gathering context information, upon which recommendations can be based from literature. It is evident and important to not treat this research as fitting for other companies as well; therefore, there still needs to be research conducted internally in other companies wishing to implement Human Factors or improve their current HF process. However, the method adapted here of using interviews to identify barriers and wishes could be used in other companies as well.

3.3.3 Conclusion. At the moment of writing this, a few meetings of the proposed HF workgroup have already taken place. These were received with enthusiasm and in good order. Other recommendations should still be tested in practice, however, a conclusion can be drawn at this stage.

In order to arrive at an answer on the goal of this research, finding feasible, effective and future-proof recommendations for the Human Factor process within Thales Hengelo, this study conducted qualitative interviews with stakeholders within the design process in order to identify barriers, wishes and context information. Applicable recommendations were derived, and the HFE, a trainer and the T & I manager have evaluated these, as it is held that these stakeholders have the most to gain from a new- HF process. Their input is therefore invaluable. To consider other stakeholders, consensus was reached through means of an extensive survey, and an offline questionnaire. Based on the comments in the evaluation interview, the level of consensus in the survey, and further recommendations, the proposed process was further complemented. An overview of the identified barriers and recommendations to mitigate these barriers, already discussed in the previous sections, can be found in Table 8. They are separated by the phases within the proposed process they occur in.

Table 8

Recommendations per process phase, aimed at mitigating the identified barriers

Process phase	Analysis	Design & Development	Test & Integration	Aftercare	Throughout the process/outside the process
Raising HF awareness and knowledge			Meeting once a month with T & I employees	Gathering user feedback several years after usage	HF workgroup; Usability champions
Deriving usability requirements	Working together with user representatives			Gathering user feedback several years after usage	
User feedback	Deriving user requirements	Involving the user			

only at the end of the design process		representatives during the PDR			
Resistance to proposed HF changes	Demonstrating good and bad examples from practice				Usability champions
HF activities in other domains					HF workgroup

Note: This table shows an overview of all recommendations which fit within a phase and address or mitigate an identified barrier. It should be emphasized however, that this table is by no means an exhaustive summary of all recommendations given and discussed in this report.

From this table, it is clear that at least every barrier is addressed by means of a recommendation, of which four of the barriers are addressed multiple times. It is theorized that these recommendations mitigate the barriers. As every barrier is addressed by at least one recommendation, it can be concluded that the recommendations cover the barriers and that the phases within the process are sufficient in this way. Enriched with the recommendations given in the evaluation by the trainer, T & I manager and HFE, the proposed process is therefore foreseen as being future-proof, as its long-term potential has been assessed, effective, as it is theorized to mitigate the identified barriers, and applicable, as it is built upon comments and consensus from various stakeholders. The conclusion is therefore that the recommendations given in this report are feasible, effective and lead to a future-proof, structured HF process for Thales Hengelo.

References

Abras, C., Maloney-Krichmar, D., & Preece, J. (2004). User-centered design. *Bainbridge, W. Encyclopedia of Human-Computer Interaction. Thousand Oaks: Sage Publications*, *37*(4), 445-456.

Altom, T. (2007). Usability as risk management. *Interactions*, *14*(2), 16-17.

Aurino, D. E. M. (2000). Human factors and aviation safety: What the industry has, what the industry needs. *Ergonomics*, *43*(7), 952-959.

Beevis, D. (2003). Ergonomics—costs and benefits revisited. *Applied ergonomics*, *34*(5), 491-496.

Belanche, D., Casaló, L. V., & Guinalíu, M. (2012). Website usability, consumer satisfaction and the intention to use a website: The moderating effect of perceived risk. *Journal of retailing and consumer services*, *19*(1), 124-132.

Bligård, L. O., & Andersson, J. (2009, September). Use errors and usability problems in relation to automation levels of medical devices. In *European Conference on Cognitive Ergonomics: Designing beyond the Product---Understanding Activity and User Experience in Ubiquitous Environments* (p. 10). VTT Technical Research Centre of Finland.

Bødker, S., & Buur, J. (2002). The design collaboratorium: a place for usability design. *ACM Transactions on Computer-Human Interaction (TOCHI)*, *9*(2), 152-169.

Booher, H. R. (1997). Human Factors Integration: Cost and Performance Benefits on Army Systems. HUGHES TRAINING INC FALLS CHURCH VA LINK OPERATIONS.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, *3*(2), 77-101.

Burgess-Limerick, R., Cotea, C., Pietrzak, E., & Fleming, P. (2011). Human systems integration in defence and civilian industries. *Australian Defence Force Journal*, (186), 51.

Chua, Z. K., & Feigh, K. M. (2011, October). Integrating human factors principles into systems engineering. In *2011 IEEE/AIAA 30th Digital Avionics Systems Conference* (pp. 6A1-1). IEEE.

Cullen, L. (2007). Human factors integration–Bridging the gap between system designers and end-users: A case study. *Safety Science, 45*(5), 621-629.

Dalkey, N., & Helmer, O. (1963). An experimental application of the Delphi method to the use of experts. *Management science*, *9*(3), 458-467.

Department of Defense, United States of America. (2019.) MIL-STD-1472-G_CHG-1 DEPARTMENT OF DEFENSE DESIGN CRITERIA STANDARD: HUMAN ENGINEERING (Standard G_CHG-1). Retrieved from http://everyspec.com/MIL-STD/MIL-STD-1400-1499/MIL-STD-1472G_CHG-1_56051/

Department of Defense, United States of America. (1996.) MIL-HDBK-46855, DEPARTMENT OF DEFENSE HANDBOOK: HUMAN ENGINEERING GUIDELINES FOR MILITARY SYSTEMS, EQUIPMENT, AND FACILITIES. Retrieved from http://everyspec.com/MIL-HDBK/MIL-HDBK-9000-and-Up/MIL-HDBK-46855_24733/

Dismukes, R. K. (2010). Understanding and analyzing human error in real-world operations. In *Human factors in aviation* (pp. 335-374). Academic Press.

Elm, W. C., Gualtieri, J. W., McKenna, B. P., Tittle, J. S., Peffer, J. E., Szymczak, S. S., & Grossman, J. B. (2008). Integrating cognitive systems engineering throughout the systems engineering process. *Journal of Cognitive Engineering and Decision Making, 2*(3), 249-273.

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of advanced nursing*, *62*(1), 107-115.

Fairbanks, R. J., & Caplan, S. (2004). Poor interface design and lack of usability testing facilitate medical error. *The Joint Commission Journal on Quality and Safety*, *30*(10), 579-584.

Forsberg, K., & Mooz, H. (1991, October). The relationship of system engineering to the project cycle. In *INCOSE International Symposium* (Vol. 1, No. 1, pp. 57-65).

Galar, D., Stenström, C., Parida, A., Kumar, R., & Berges, L. (2011, December). Human factor in maintenance performance measurement. In *2011 IEEE International Conference on Industrial Engineering and Engineering Management* (pp. 1569-1576). IEEE

Gawron, V. J., Drury, C. G., Fairbanks, R. J., & Berger, R. C. (2006). Medical error and human factors engineering: where are we now?. *American Journal of Medical Quality*, *21*(1), 57-67.

Gramopadhye, A. K., & Drury, C. G. (2000). Human factors in aviation maintenance: how we got to where we are. *International Journal of Industrial Ergonomics*, *26*(2), 125–131. doi: 10.1016/s0169-8141(99)00062-1

Hobbs, A. (2008). An overview of human factors in aviation maintenance. *ATSB Safty Report, Aviation Research and Analysis Report AR*, *55*, 2008.

Høegh, R. T. (2008). Case study: integrating usability activities in a software development process. *Behaviour & Information Technology*, *27*(4), 301-306.

ISO 6385:2016. (2016, September 14). Retrieved August 02, 2020, from https://www.iso.org/standard/63785.html

Karat, C. M. (1990, October). Cost-benefit analysis of usability engineering techniques. In *Proceedings of the Human Factors Society Annual Meeting* (Vol. 34, No. 12, pp. 839-843). Sage CA: Los Angeles, CA: SAGE Publications.

Karsh, B. T., Holden, R. J., Alper, S. J., & Or, C. K. L. (2006). A human factors engineering paradigm for patient safety: designing to support the performance of the healthcare professional. *BMJ Quality & Safety*, *15*(suppl 1), i59-i65.

Kirwan, B., Evans, A., Donohoe, L., Kilner, A., Lamoureux, T., Atkinson, T., & MacKendrick, H. (1997, June). Human factors in the ATM system design life cycle. In *FAA/Eurocontrol ATM R&D Seminar, Paris, France* (pp. 16-20).

Landsburg, A. C., Avery, L., Beaton, R., Bost, J. R., Comperatore, C., Khandpur, R., ... & Sheridan, T. B. (2008). The art of successfully applying human systems integration. *Naval Engineers Journal, 120*(1), 77-107.

MacKenzie, I. S., & Zhang, S. X. (1999, May). The design and evaluation of a high-performance soft keyboard. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems* (pp. 25-31).

Majid, R. A., Noor, N. L. M., Adnan, W. A. W., & Mansor, S. (2010). A survey on user involvement in software development life cycle from practitioner's perspectives. In *5th International Conference on Computer Sciences and Convergence Information Technology* (pp. 240-243). IEEE.

Mayhew, D. J. (1999). Business: Strategic development of the usability engineering function. *Interactions*, *6*(5), 27-34.

McDaniel, J. W. (1996). The demise of military standards may affect ergonomics. *International journal of industrial ergonomics, 18*(5-6), 339-348.

McNamara, L. A., & Klein, L. M. (2016, May). Context-sensitive design and human interaction principles for usable, useful, and adoptable radars. In *Radar Sensor Technology XX* (Vol. 9829, p. 982906). International Society for Optics and Photonics.

Money, A. G., Barnett, J., Kuljis, J., Craven, M. P., Martin, J. L., & Young, T. (2011). The role of the user within the medical device design and development process: medical device manufacturers' perspectives. *BMC medical informatics and decision making*, *11*(1), 15.

Mrazek, D., & Rafeld, M. (1992, June). Integrating human factors on a large scale: product usability champions. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 565-570).

North, B. (2015). The growing role of human factors and usability engineering for medical devices. *What's required in the new regulatory landscape*.

van der Peijl, J., Klein, J., Grass, C., & Freudenthal, A. (2012). Design for risk control: the role of usability engineering in the management of use-related risks. *Journal of biomedical informatics*, *45*(4), 795-812.

Polisena, J., Castaldo, R., Ciani, O., Federici, C., Borsci, S., Ritrovato, M., ... & Pecchia, L. (2018). Health technology assessment methods guidelines for medical devices: how can we address the gaps? The International Federation of Medical and Biological Engineering perspective. *International journal of technology assessment in health care*, *34*(3), 276-289.

Poltrock, S. E., & Grudin, J. (1994). Organizational obstacles to interface design and development: two participant-observer studies. *ACM Transactions on Computer-Human Interaction (TOCHI), 1*(1), 52-80.

Razzak, M., Islam, M.N. Exploring and Evaluating the Usability Factors for Military Application: A Road Map for HCI in Military Applications. *Hum Factors Mech Eng Def Saf 4*, 4 (2020).

Reason, J. (1990). *Human error*. Cambridge university press.

Rosenbaum, S., Rohn, J. A., & Humburg, J. (2000, April). A toolkit for strategic usability: results from workshops, panels, and surveys. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems* (pp. 337-344).

Scholtz, J. (2004). Usability evaluation. *National Institute of Standards and Technology*, *1*.

Shackel, B. (2009). Usability–Context, framework, definition, design and evaluation. *Interacting with computers*, *21*(5-6), 339-346.

Sheikhalishahi, M., Pintelon, L., & Azadeh, A. (2016). Human factors in maintenance: a review. *Journal of Quality in Maintenance Engineering*.

Stark, R. F., & Kokini, C. (2010). Reducing risk in system design through human-systems integration. *Ergonomics in Design*, *18*(2), 18-22.

Simões, J. M., Gomes, C. F., & Yasin, M. M. (2011). A literature review of maintenance performance measurement. *Journal of Quality in Maintenance Engineering*, *17*(2), 116-137.

United States of America, Food and Drug Administration. (2016, February 03). *Applying Human Factors and Usability Engineering to Medical Devices*. Retrieved from https://www.fda.gov/media/80481/download

Village, J., Searcy, C., Salustri, F., & Patrick Neumann, W. (2015). Design for human factors (DfHF): a grounded theory for integrating human factors into production design processes. *Ergonomics, 58*(9), 1529-1546

Vredenburg, K. (2002). Designing the total user experience at IBM: An examination of case studies, research findings, and advanced methods. *International Journal of Human-Computer Interaction, 14*(3-4), 275-278.

Vredenburg, K., Mao, J. Y., Smith, P. W., & Carey, T. (2002, April). A survey of user-centered design practice. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 471-478).

Waterson, P., & Kolose, S. L. (2010). Exploring the social and organisational aspects of human factors integration: A framework and case study. *Safety Science, 48*(4), 482-490.

Wie zijn wij? (n.d.). Retrieved March 5, 2020 from https://www.thalesgroup.com/en/worldwide/careers/wie-zijn-wij

Tables

Table 1.

Recommendations for an HF approach derived from the literature

Recommendations	**Source**
Early integration of HF in the design process	Abras, Maloney-Krichmar and Preece, (2004, amongst others; for full list, see text)
Distinction between the different maintenance activities and aspects from job context	Sheikhalishahi, Pintelon and Azadeh (2016)
Use user feedback	Karsh, Holden, Alper and Or (2006)
Feedback loop within the HF process	Karsh, Holden, Alper and Or (2006)
Check how risk and usability are being treated; differs across industries	North (2015), Stark and Kokini (2010)

Table 2.

Identified barriers of HF integration

Barriers	**Source**
Organizational structure: HF low in hierarchy	Waterson and Kolose (2010)
Organizational culture: ‘engineering worldview’	Waterson and Kolose (2010)
Team performance: degree to which HF supports organizational goals or company business objectives	Waterson and Kolose (2010)
Team viability: sustainability of collaboration with other groups over time	Waterson and Kolose (2010)
Attitudes and perceptions: HF seen as expensive	Waterson and Kolose (2010)
Information and data problems	Waterson and Kolose (2010)
Rewards and recognition: lack of support from top managers	Waterson and Kolose (2010)
Training and education: HFE’s have different background than other engineers	Waterson and Kolose (2010)
Convincing upper management of HF importance is difficult	Altom (2007)

Table 3.

Number of participants mentioning the identified barriers

Theme	Number of participants (out of 8)
HF knowledge and awareness sparse	3
Usability requirements are not being considered	3
User feedback at the end of the process	4
Resistance to changes aimed at improving usability	3
HF practices and activities carried out in other domains	3

Table 4.

Recommendations per proposed process phase

Recommended process step	Recommended activities
Throughout the process	HF workgroup, Usability champions, HF database
Analysis	Situational Awareness Analysis, Cognitive Task Analysis, Human Performance Reliability Analysis, Diagram method, Timeline diagram, Action/Information requirements, Workload analysis, Link analysis, Mission analysis, Design criteria checklist
Design & Development	Drawings, mock-ups, scale models, interview with user (representative), using questionnaires, secondary task monitoring
Test & Integration	Set meeting point between HFE and T&I
Aftercare	HF workgroup

Table 5.

Main findings of the offline questionnaire

Recommendation	Consensus
Usability champions	Good idea; but see it as a means toward improved HF awareness
Number of phases in the proposed process	Sufficient in this way
Cognitive methods	Useful to execute; most applicable is situational awareness analysis
Diagram methods	Torn between operational sequence, flow-process chart and Decision/Action diagram
Judge per project which method is most applicable	Emphasized by others as well, a good argument needs to be made

Table 6.

Main findings of the structured interviews

Question	Answer from the participants
Process sufficient in this way?	More set contact points early on in the process
Gap between theory and practice mitigated?	Dependent on the level of representation
Room for sufficient user feedback?	Visual aids may help
HF awareness within the departments?	Already maximum, but meeting points may help with bringing awareness to young and new employees

Table 7.

Results of the online survey

Recommendation	Median	IQR	Recommendation kept?
HF workgroup	6	0	Yes
Usability champions	5,50	1	Yes
HF database	6	3	Yes
Situational Awareness analysis	6	0,75	Yes
Cognitive task analysis	5	2	Yes
Human Performance Reliability Analysis	5	3	Yes
Diagram method	6,50	1,75	Yes
Timeline diagram	3,50	1,75	Yes
Action/information requirements	6	2	Yes
Workload analysis	2,50	1,75	No
Link analysis	5,50	1,75	Yes
Mission analysis	6	0,75	Yes
Design criteria checklist	5,50	1	Yes
Drawings	5	2	Yes
Mock-ups	6	0	Yes
Scale models	6	0,75	Yes
Interview with user (representative)	5,50	1,75	Yes
Using questionnaires	4	1	Yes
Secondary task monitoring	2,50	1	No
Set meeting point between HFE and T&I	6,50	4	Yes

Note: Answers were given via a 7-point Likert scale, where 1 was set as not useful at all, and 7 as very useful.

Table 8

Recommendations per process phase, aimed at mitigating the identified barriers

Process phase	Analysis	Design & Development	Test & Integration	Aftercare	Throughout the process/outside the process
Raising HF awareness and knowledge			Meeting once a month with T & I employees	Gathering user feedback several years after usage	HF workgroup; Usability champions
Deriving usability requirements	Working together with user representatives			Gathering user feedback several years after usage	
User feedback only at the end of the design process	Deriving user requirements	Involving the user representatives during the PDR			
Resistance to proposed HF changes	Demonstrating good and bad examples from practice				Usability champions
HF activities in other domains					HF workgroup

Note: This table shows an overview of all recommendations which fit within a phase and address or mitigate an identified barrier. It should be emphasized however, that this table is by no means an exhaustive summary of all recommendations given and discussed in this report.

Figures

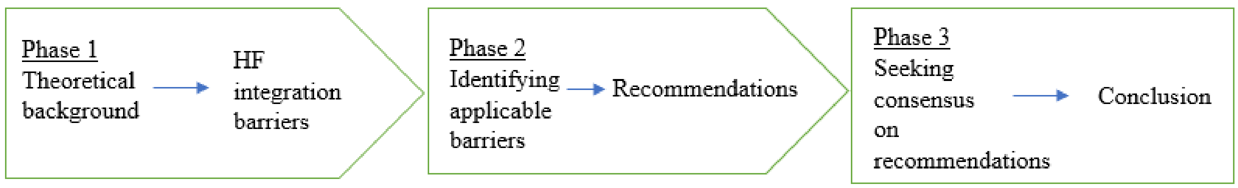

Figure 1. The three phases of the report with main component, and the result of the phase, which ties into the next phase.

Figure 2. Framework indicating the social and organizational aspects of HF integration on an individual, team and organizational level (derived from Waterson & Kolose, 2010).

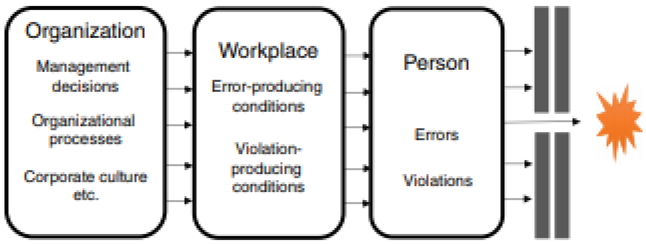

Figure 3. Combining the three literature categories in the Swiss Cheese model. Derived from Sheikhalishahi, Pintelon and Azadeh (2016).

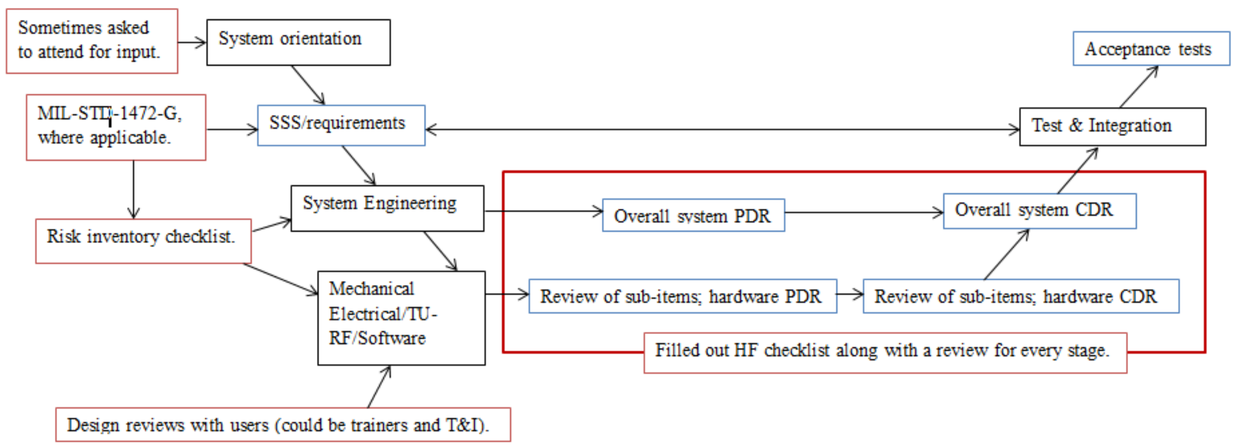

Figure 4. The current design process within Thales Hengelo. HF activities are outlined in red, steps in which a launching customer are involved are outlined in blue. The explanation below starts at the first phase, System Orientation, and follows the arrows all the way to Acceptance tests.

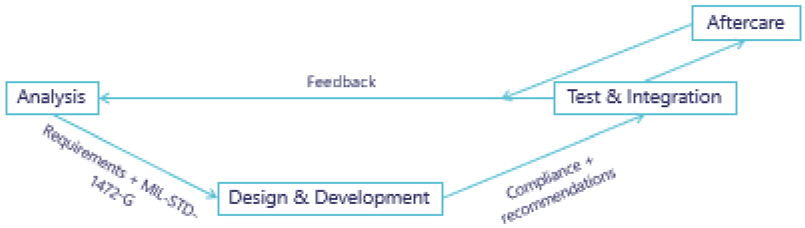

Figure 5. The proposed HF process.

Appendices

Appendix A – interview questions

1. What is your role within the design process?
2. What are the relationships to HF?
3. What input or output from HF is convenient for your discipline?
4. Are there any activities within your discipline which bear resemblance to HF activities?
5. How often do you have contact with the HFE?

Appendix B – list of the proposed recommendations

1. HF workgroup
2. Usability champions
3. HF database
4. Situational Awareness Analysis
5. Cognitive Task Analysis
6. Human Performance Reliability Analysis
7. Diagram method
8. Timeline diagram
9. Action/information requirements
10. Workload analysis
11. Link analysis
12. Mission analysis
13. Design criteria checklist
14. Drawings
15. Mock-ups
16. Scale models
17. Interview with user (representative)
18. Using questionnaires
19. Secondary task monitoring
20. Set meeting point between HFE and T & I

Appendix C – offline questionnaire questions

1. What do you think of the phases Analysis, Design & Development, Test & Integration and Aftercare? Should some of them be combined or should there be more phases?
2. How do you judge the applicability of especially the Situational Awareness method, but also the other cognitive methods during the Analysis phase? Can be found on slide 9.
3. Which diagram method in the Analysis phase would be the most convenient/applicable?
4. Would you recommend to also always use a method on the Analysis phase- possibly of value slide (nr. 14)?
5. Are there any further suggestions to methods used in the Design & Development phase?
6. Are there other stakeholders which I have not considered/addressed in the presentation?
7. Do you think the Aftercare and T&I phases could/should be combined?
8. Do you think the use of usability champions/sponsors can be implemented?
9. Are there any overlaps with your discipline?
10. Do you have any comments/additions to the overall process recommendations?
11. Any other feedback regarding the presentation which has not been covered by the above questions?

Appendix D – online survey questions

1. Select the most appropriate discipline within Thales Hengelo under which your job falls:

   Specialty Engineering

   Logistic Engineering

   Test & Integration

   Architect

   Trainers

   Other, namely:

2. A recommendation is the setting up of a Human Factor workgroup. The workgroup here is defined as a group of stakeholders which meet regularly and discuss Human Factor issues within their domains. How useful would such a workgroup be for your job?

   1 = not useful at all, 7 = very useful.

3. Another recommendation is having usability champions/sponsors. These are higher-ups who are sponsoring improving usability within designs. How useful would a usability sponsor be for your job?

   1 = not useful at all, 7 = very useful.

4. A recommendation is a Human Factor database. This database contains general Human Factor information such as MIL-STD-1472-G_CHG-1, and frequent Human Factor issues, accessible to everyone to check. If we were to implement such a database, how useful would that be for your job?

   1 = not useful at all, 7 = very useful.

5. Situational awareness: “a person’s perception of elements in the environment, comprehension of that information, and the ability to project future events based on this

understanding" (Wright, Taekman & Endsley, 2004). Do you think a method which gathers information on such situational awareness would be useful for your job?

1 = not useful at all, 7 = very useful.

6. Cognitive task analysis: "a set of methods for identifying cognitive skills, or mental demands, needed to perform a task proficiently" (Militello & Hutton, 1998). Do you think cognitive task analysis would be useful for your job?

   1 = not useful at all, 7 = very useful.

7. Human Performance Reliability Analysis: "assessing the human reliability to reduce the probabilities of important human errors to some acceptable minimum" (Swain, 1990). Would such a Human Performance Reliability Analysis be useful in your job?

   1 = not useful at all, 7 = very useful.

8. Do you have a preference for one of the methods above (Situational Awareness, Cognitive Task Analysis, and Human Performance Reliability Analysis)?

9. A diagram method can be used to map out what tasks the user needs to do, what is needed for said task and to create an overview of necessary requirements. Would such a diagram method be useful for your job?

   1 = not useful at all, 7 = very useful.

10. Below there are four different diagram methods. Each have their own properties and differences. If you have a preference for one of them, please select that diagram. If not, click the I don't know option.

11. A timeline diagram shows how long it takes for the user to execute a certain task. Would such a timeline diagram be useful for your job?

    1 = not useful at all, 7 = very useful.

12. Action/information requirements specify which specific actions are needed to perform a function, and which information the user needs to decide to execute these actions. How useful would such requirements be for your job?

    1 = not useful at all, 7 = very useful

13. Workload analysis: assessing the experienced workload by a user; the extent of user loading based on the sequential accumulation of task times. How useful would such an analysis be for your job?

    1 = not useful at all, 7 = very useful

14. Link analysis: analysing which elements in an environment should be placed close together to convenience of the user, as to design an optimal layout. How useful would such a link analysis be for your job?

    1 = not useful at all, 7 = very useful.

15. Mission analysis: used to define what tasks the total system must perform, starting from the general level down to a specific level, which can be used to establish Human Factor design criteria. How useful would mission analysis be for your job?

    1 = not useful at all, 7 = very useful

16. A design criteria checklist contains all the requirements derived from the Analysis phase, and can be used to check compliance. How useful would such a checklist be for your job?

    1 = not useful at all, 7 = very useful.

17. Drawings here mean that users (or representatives of users) and the Human Factor Engineer judge drawings of the design for usability issues. How useful would that be for

your job?

1 = not useful at all, 7 = very useful.

18. Mock-ups can be used to test the design for usability. How useful would that be for your job?

    1 = not useful at all, 7 = very useful.

19. Scale models can be used to also uncover usability issues. How useful would that be for your job?

    1 = not useful at all, 7 = very useful.

20. Interviewing the user (or user representative) after a user test on issues can uncover usability problems. How useful would that be for your job?

    1 = not useful at all, 7 = very useful.

21. Using questionnaires with users (or representatives) after a user test can also help to uncover usability issues. How useful would that be for your job?

    1 = not useful at all, 7 = very useful

22. Secondary task monitoring is a method which measures the user's workload, and can be used when in the Analysis phase a workload analysis has been conducted. How useful would that be for your job?

    1 = not useful at all, 7 = very useful.

23. We want to have a set meeting point between Test & Integration and the Human Factor Engineer to discuss Human Factors issues found during testing and to raise the awareness of Human Factors. How useful would that be for your job?

    1 = not useful at all, 7 = very useful.

24. Do you have any comments or feedback regarding this proposed Human Factor process and the recommendations/methods in it?

Appendix E – structured interview questions

1. Is the gap between theory and practice sufficiently closed in the proposed process? Why (not)?
2. Do you foresee this process working on the long term? Why (not)?
3. Is there enough room to consider the user within this process? Why (not)?
4. Do you think this will generate sufficient user feedback on the design? Why (not)?
5. What, would you say, are the biggest causes of errors by maintainers? Examples of causes can be insufficient knowledge, design flaws, etc.
6. Do you think that concrete user requirements can be formulated within this process? Why (not)?
7. Will this process help improve usability? Why (not)?
8. Do you think this will raise awareness of HF within your own department? Why (not)?
9. Lastly, are there any changes or adaptations necessary to make this process successful? What would you like to see?