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Human performance tools in nuclear power plant maintenance activities
Final report of HUMAX project

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Abstract

In recent years most Nordic nuclear power plants have implemented so called human performance programmes. Typically human performance programmes apply *human performance tools (HU tools)* to maximize failure free operations by preventing and/or catching human errors. Despite the prominence of human performance programmes, there is little scientific literature on the premises behind the HU programmes. Also, the concrete beneficial effects from using HU tools in nuclear power plants remain elusive. This document describes the results of a Nordic research project HUMAX which aims at providing knowledge of the impacts of the HU programmes and to support implementation of effective HU tools. The focus is especially on maintenance activities.
In 2013 and 2014 HUMAX project carried out three case studies in Nordic nuclear power plant maintenance. Furthermore HUMAX disseminated an international survey to human performance experts around the world to gain insights into the motives underlying the human performance programmes and the benefits received.
The results show that HU tools are introduced as error prevention techniques and it is believed that reducing the number of human errors improves nuclear safety. However, the study suggests that it may be difficult to prove measurable improvements in nuclear safety indicators. The benefits of HU tools included other than directly nuclear safety related benefits such as decreased number of occupational safety incidents and less rework. There was a general fairly positive attitude towards the use of HU tools amongst the maintenance personnel when the tools were seen as supporting the quality of work rather than as controlling methods. If not carefully planned, HU tools may complicate and slow down work processes and cause frustration among workers. A risk that task execution becomes mechanistic and HU tools dampen workers' self-initiative was reported. In order to facilitate mindful use of the tools it is crucial that the implementation process starts by thorough discussion on why, how and when each of the tools should be used in the unique cultural context. HU tools should not be used for compensating system problems, such as poor working conditions. The results of the study have been summarised in a set of recommendations to support the HU programme implementation process.

Key words

human error, nuclear power, safety culture, safety management, maintenance

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Abstract

In recent years most Nordic nuclear power plants have implemented so called human performance programmes. Typically human performance programmes apply predefined *human performance tools (HU tools)* to maximize failure free operations by preventing and/or catching human errors. Despite the prominence of human performance programmes, there is little scientific literature on the basic premises behind the HU tools. Also, the concrete beneficial effects from using HU tools in nuclear power plants remain elusive. This document describes the results of joint Nordic research project HUMAX which aims at providing knowledge of the impacts of the human performance programmes and to support the designing and implementing effective HU tools. The focus is especially on maintenance activities.

In 2013 and 2014 HUMAX project carried out three in-depth case studies in Nordic nuclear power plant maintenance organisations and studied the expected and experienced benefits of HU tools as well as personnel opinion on the HU programme. Furthermore HUMAX disseminated an international survey to human performance experts around the world to gain more insight into the motives underlying the human performance programmes and the benefits received.

The results show that HU tools are introduced as error prevention techniques and it is believed that reducing the number of human errors improves nuclear safety. However, the study suggests that it may be difficult to prove measurable improvements in commonly used nuclear safety indicators, such as number of scrams. The concrete benefits of HU tools included also other than directly nuclear safety related benefits such as decreased number of occupational safety incidents and less rework. There was a general positive or neutral attitude towards the use of HU tools amongst the maintenance personnel when the tools were seen as supporting the quality of work rather than as controlling methods. If not carefully planned, using HU tools may complicate and slow down work processes and cause frustration among workers. A risk that task execution becomes mechanistic and HU tools dampen workers' self-initiative was reported. In order to facilitate flexible and mindful use of the tools it is crucial that the implementation process starts by thorough discussion on why, how and when each of the tools should be used in the unique cultural context. HU tools should not be used for compensating system problems, such as poor working conditions. The results of the study have been summarised in a set of recommendations to support the HU programme implementation process.

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Abbreviations

HU	Human Performance
HU tools	Human Performance tool
IFE	Institutt for Energiteknikk

Contents

1. Introduction

In nuclear power plants effective and reliable maintenance is crucial for safe operation. Maintenance provides the technical preconditions for undisturbed operations and functioning of the safety systems. In many safety-critical domains, like aviation, offshore oil drilling, chemical, petrochemical, railway and nuclear industries inadequate or faulty maintenance has been found as one of the main contributors to events by accident investigations (see e.g., Reason 1997, Hale et al. 1998, Kletz 2003, Reason & Hobbs 2003, Perin 2005, Baker 2007, Sanne 2008). It is recognized that effective maintenance activities produce reliable results when technical, human and organisational factors are all considered (Reason 1997, Reiman 2011).

Many safety management systems include today the so called human performance program, a set of activities dedicated to improve safety through human behaviour. According to the Department of Energy (DOE), human performance programs have two main objectives: to *reduce errors*, and to *strengthen controls* (DOE, 2009). In recent years most Nordic nuclear power plants have been implemented human performance programs following the guidance e.g. from INPO (1997, 2006), DOE (2009) and IAEA (2001, 2005). Typically human performance programs apply predefined ***human performance tools*** (HU tools). HU tools are simple aids or working methods to be used by managers and supervisors, engineers and workers, although front line workers, usually maintenance and control room workers, most often are in focus. Examples of HU tools are peer checking of work, three-way-communication, pre-job-briefing and supervisor's task observations (DOE 2009b).

In the nuclear industry human performance programs have mainly been developed by practitioners, and disseminated through informal networks and international bodies such as INPO (1997, 2006) and WANO (e.g., 2002, 2006). The human performance programmes have developed fairly independently from *human factors discipline*, since in the nuclear industry the human performance programmes are often developed and implemented by engineers, whereas human factors community involves behavioural and social scientists.

During the years the use of HU tools has become a popular at nuclear facilities. Despite the popularity, two main issues remain:

- There is little scientific literature on the basic premises behind the HU tools
- The concrete beneficial effects from using human performance tools in nuclear power plants remain elusive.

Human performance programmes are partially based on the so-called *behavioural safety* approach. This approach has been commonly applied e.g. in the petrochemical industry since the 1990's (for an overview see e.g. Geller 2005, Tuncel et al. 2006, DeJoy 2005). The behavioural safety approach has lately been criticised (e.g. Hopkins 2006, Le Coze 2008, Anderson 2007). One of the concerns is that behaviour focused programs may direct the attention towards individual workers instead of, for example, poor design or suboptimal organisation of the work. Hopkins (2006) states that: *"The reality is that unsafe behaviour is merely the last link in a causal chain and not necessarily the most effective link to focus on, for the purposes of accident prevention".*

In addition, by focusing on front line workers behavioural safety programs may foster a blaming culture rather than enhance the development of a good safety culture. Organisational trust is a key factor in successful behavioural safety programs, but it has not been accomplished in all organisations (Cox 2004). A further concern is that behavioural safety programs may focus on occupational (personnel) safety rather than system safety, since it is much easier to judge the safety or riskiness of behaviours in relation to occupational safety than in relation to system safety. Anderson (2007) states that *"these programs tend to focus on intuitive issues and personal health and safety, ignoring low probability/high consequence risks".*

An interesting question concerns the human performance programme's primary goal of strengthening controls (DOE 2009a). Safety scientists, especially the proponents of the *Resilience Engineering* approach, suggest that this strategy has limitations (Woods et al. 2010, Hollnagel 2009). When safety controls are too rigid, smooth execution of the work becomes more complicated and the likelihood of 'cutting corners behaviour' increases. Further, the resilience engineering theory claims that the variations in the performance of workers should not be totally eliminated since variability gives rise to flexibility and thus ability to cope with unexpected and novel situations. Even in the highly standardized and proceduralised industrial settings, like the nuclear industry, the army, the aviation maintenance etc. local adjustments take place frequently (Bourrier 1996, Snook, 2000). This was identified also in the NKS-study MOREMO (Oedewald et al. 2012, Gotcheva et al. 2013) that analysed maintenance working practices in Nordic power plants.

Due to the above mentioned concerns towards the impacts of error and behaviour focused safety approaches it is worth analysing the rationale and use of the HU tools in the nuclear industry. It should be better understood why the tools are implemented and does the way they are implemented affect the impacts these tools have in the organisation. By now, nuclear industry organisations have experience on about their use and this allows us to study what the benefits and downsides of the tools have been. There have been concerns amongst practitioners that organisations do not always adopt human performance tools without internal criticism. It has been claimed that the human performance tools take too much time to apply or the methods feel clumsy or naïve for the workers. It is possible, that some of the tools which fit well for the working culture of Anglo-American companies are awkwardly perceived in the Nordic working culture where supervisory control is less prominent and employee's professionalism is highly valued. The question thus is how to apply HU tools in your environment effectively, without complicating too much the work and allowing sufficient amount of flexibility in the performance.

2. Goals, research strategy and data collection

The goals of the study are to provide knowledge of the impacts of the human performance programmes and to support the design and implementation of effective human performance tools in Nordic nuclear plant for maximizing the benefits on safety and reducing possible shortcomings.

The research questions are:

1. What are the expected benefits of human performance tools applied in nuclear power plant maintenance?
2. What have the measurable benefits of human performance tools been so far in the plants (e.g. reduced number of failures, reportable licensee event reports, human errors)?
3. How do maintenance personnel perceive the application and effects of human performance tools?
4. What characterizes successful human performance tools and implementation processes?
5. What aspects of maintenance work are most effectively met by use of human performance tools, and what could be solved by other socio-technical means?

The study was carried out by two research institutes (IFE and VTT) and an expert from a power company (Vattenfall). The research strategy was to carry out *three case studies at Nordic nuclear power plants* and to complement that view with insights gained from *an international survey*. In addition to that a literature review into human performance tools and other means to deal with human errors was carried out.

Case studies were conducted in three Nordic nuclear plants in Sweden and Finland. These Nordic power companies were selected for practical reasons: the study was part of a Nordic research programme and the researchers had good relationships with the Nordic power companies. In order to ensure the validity of the study and to gain knowledge on possible national culture differences the international survey was introduced.

The scope of the study was maintenance activities because A) we wanted to narrow down the scope in order to discuss the practical application situations, error mechanisms, implementations challenges and benefits as concretely and thorough as possible and B) Human performance tools are typically implemented in maintenance activities since the work involves plenty of possibilities for human errors with significant consequences on plant availability and safety.

2.1 **Data collection in the case studies**

The three Nordic case organisations differed in certain respects. Two of the plants had implemented human performance programmes i.e. had set clear expectations and provided training for the personnel to use certain human performance tools. One of the plants had not yet implemented a human performance programme, although they have adopted many similar practices throughout the years. They had, however, started a project where the aim was to decide a strategy to systematically implement selected set of human performance tools. The case organisations had also selected slightly different tools to be included in their human performance programmes (Table 1). It has to be mentioned that Plants A and B did talk about questioning attitude and they do have operating experience practices but do not consider those as HU tools. Same applies to STAR-principle at plant B.

Table 1. *The HU tools selected to be used at the case organisations. Note that the organisation A had not started the implementation yet.*

HU tool	Plant A	Plant B	Plant C
Pre-job brief	(√)	√	√
Post job review	(√)	√	√
Independent verification	(√)	√	√
Peer checking (pair work)	(√)	√	√
Clear communication techniques (e.g. three way, phonetic alphabets)	(√)	√	√
STAR/two minute rule	(√)		√
Procedural Use and Adherence			√
Questioning Attitude			√
Task Observation/Coaching			√
Use of Operating Experience			√

The data collection in the Nordic case studies included interviews, questionnaire survey in two cases, document analysis and some observations. Altogether 47 interviews were carried out. The interviewees included maintenance supervisors and managers, technicians and electricians. Couple of control room operators were interviewed as well. In two of the plants also a personnel survey was utilised to gather personnel opinions on their HU programme (in plants B and C). Furthermore, researchers familiarised themselves with the relevant documentation concerning the HU programmes and discussed the research questions with the case study HU coordinators frequently. The researchers also observed some work tasks during an annual outage at the plant B and discussed with the personnel on their experiences concerning the HU tools.

Since the case study plants had different experience on the HU tools and different practical expectations for the study the data collection was not consistent, i.e. the interview questions were modified from case to case and the personnel survey was not used in case A (where they had no formal HU programme). During the analysis these different emphasis were taken into considerations and the lessons learned from each case were integrated.

2.2 Data collection from the international survey

A self-administered web questionnaire was disseminated to nuclear industry human performance experts around the world. The rationale for this was to gain a broader data set and better understanding on the expected and measured benefits, experiences on HU programmes and knowledge on success factors of the implementation. It was assumed that in many countries the HU programmes have been utilised for a longer period of time than in Nordic countries. One of the purposes was also to understand whether there are national culture differences, or more specifically, whether HU tools are received better or worse elsewhere in the world than in Nordic countries.

The survey questionnaire web link was sent to group of individuals who had participated in various human performance seminars and networks. We used mailing lists of those forums to reach experts from different countries. We did not aim to reach all the utilities around the world, rather we hoped for getting couple of dozens of answers to complement our primary data of three Nordic plants. We instructed the receivers to skip or redirect the survey if they are not involved with nuclear industry and HU programmes.

The survey received 135 responses of which 95 responses were valid. The respondents were from at least 47 organisations (many of the respondents didn't indicate their organisation) in at least 13 different countries (some of the respondents didn't mention their country). Responses from individuals not working with human performance programs at nuclear facilities were excluded. A total of 67 full responses from individuals that work with human performance programmes in nuclear power plants were utilized in the analysis. The respondents were from USA, Canada, United Kingdom, Sweden, France, Belgium, Germany, Slovenia, Spain, Finland, Hungary, Republic of Korea, Switzerland, and "International". The survey therefore comprises mainly of regional and cultural aspects associated with Northern America and European countries. Examples of countries not present in the results are Brazil, China, India, Japan, Pakistan and Russia.

For many European countries there were one or two responses. In some cases the respondent was in a position that he/she oversaw a large number of facilities and their human performance programmes. Majority of the respondents (50/67) worked at nuclear power plants, some at corporate fleet level and a few at nuclear service companies. The respondents had various occupational backgrounds and included for example human performance programme leads, safety engineers, supervisors, managers and training professionals.

The international survey data and the main results are presented in Appendix 1.

3. Results and Discussion

3.1 What are the expected benefits of human performance tools applied in nuclear power plant maintenance?

3.1.1 HU tools aim at improving safety through reducing errors and unwanted safety events

HU tools are implemented in nuclear power plants *mainly to promote safety* (both plant safety and occupational safety). The logics seems to be that HU tools help in preventing human errors which leads to reduced number of unwanted events, and this would mean improved safety. This conclusion is based on data obtained from interviews at the Nordic plants and the international survey, and it follows the logics provided by the industry literature on HU tools (e.g. DOE 2009). The international survey contained the following question: *What do you see as the main purpose of introducing Human Performance Tools in maintenance work?* The by far most dominant answer to this question was that HU tools contributed to reduce human errors and/or to prevent unwanted events (see Appendix 1).

The Nordic case studies showed that maintenance work include multiple different types of 'human errors' i.e. situations where human activity has led to unwanted outcomes, or would have led unless it was prevented by a safety barrier. For example, in the plant A the most often mentioned human error was unsuccessful torqueing; they had leaking valves and flanges after maintenance activities (Oedewald et al. 2014). Other types of errors included damaging an object while lifting, failure to comply with procedures, failure to isolate or drain a system, working on wrong equipment or at wrong unit. Examples were given on what Reason (1997) calls skill-based, rule-based and knowledge-based errors. All these error types have still very different error mechanisms i.e. contextual or psychological phenomena that contribute to the course of actions. Thus, it is important to notice that not all HU tools help in reducing all types of errors. They are not a cure for all 'behavioural ills'. The study indicated, however, that HU tools are sometimes implemented without careful discussion on what types of erroneous actions each of the tools should prevent.

Another important lesson learned from the case study A was that many of the interviewees were uncomfortable in labelling the maintenance related events as human errors since technical or contextual issues often contributed to the unsuccessful outcome. They felt that some of the problems are technical system features rather than human errors. An example given on this was the leak which was attributed to human error in torqueing. Some of the interviewees explained that leaks can sometimes occur in an old unit due to heat expansion when the unit starts up after the outage. They are aware of that possibility and fix the problem as soon as it realizes, and thus, they felt it is not accurate to label that as a human error.

Overall, the use of HU tools at the Nordic plants was mainly – but not exclusively - associated with task performance in the *sharp end*, i.e., maintenance personnel's execution of tasks in the plant. It was found that plant managers believed that the use of HU tools would contribute to promote safety by increasing the likelihood that operational tasks would be carried out according to required safety expectations at the plant, such as documented in procedures and rules. The implementation of HU tools also requires the organisation to set more explicit behavioural expectations, which was seen as one of the benefits in itself.

In the interviews some viewpoints were expressed that the relationship between HU tools and safety of the nuclear plant was not straightforward because the plant has already been designed in such a manner that single errors – which the HU tools aim at catching – would not cause significant safety effects anyway. Thus, these respondent argued that the rationale for introducing HU tools should be something else than improving nuclear safety.

3.1.2 **HU tools may serve more purposes than improving safety**

Searching for an answer to the research question "What are the expected benefits of human performance tools" led us to an interesting finding. Although the promotion of safety is the main goal of using HU tools, the tools were also perceived to serve a range of other purposes of which some were not directly phrased in terms of events and plant safety. These included:

- Minimized rework
- Less accumulated doses due to e.g. quicker task execution
- Less issues with the regulator due to procedure compliance problems
- Improved equipment performance
- Sharing knowledge and insights (e.g. Peer Checking, Pre-Job Briefings)
- Improved business performance

In the interviews at the Nordic plants, the expected benefits were often discussed in terms of smooth execution of the work with good quality, and thus, less rework. In relation to the execution of complex, infrequent tasks, which involves several persons the use of the HU tool *Pre-Job Briefing* was for example highlighted as a useful tool to support *coordination*. In relation to this type of tasks poor coordination may lead to unwanted outcomes, e.g., delays, due to unforeseen relationships between the sub-tasks, shortage of staffing with particular competence, etc. This type of delays are costly and also a source of frustration for the personnel. This type of consideration was most a contributing reason why *Pre-Job Briefing* was used at all plants participating in the International survey (who responded to the particular question, see Appendix A) – as the only HU tool.

The finding that HU tools may be used for other purposes than safety concerns were even more pronounced at the Nordic plant A where the personnel had *not* undergone human performance training. There the maintenance personnel and managers did not perceive classical active human errors to be a very big issue for them. Rather, they talked about poor coordination between workgroups and lack of preparation before going to the field, misunderstandings in communication situations, misinterpreting the instructions as factors affecting the quality and smoothness of the execution of the work.

Still, despite the above distinction between expectations associated with safety and other type of concerns, we believe that all of the issues raised by the respondents and interviewees may best be considered as two sides of the same coin:

safety and effectiveness. One respondent in the international survey expressed it this way:

> *"By reducing the number of errors, both on the job and off the job, our organization is less prone to safety incidents and more productive".*

Thus, if a task is executed "right," then safety will be ensured. If a task is executed "right the first time," then both safety and efficiency will be ensured.

3.1.3 **HU tools are expected to achieve their purpose by …**

The exact way in which HU tools were expected to achieve their purpose was perceived differently by the respondents. The likely most frequent expectation was that HU tools introduced *check points* in or in relation to (e.g., prior) task execution processes, which implied that errors would be identified and prevented. *Peer Checking*, *Self-checking - STAR*, and *Independent Verification* were typical HU tools presented to illustrate that HU tools achieved their purpose in this way. This conception of how HU tools achieved their purpose implied that HU tools mainly were seen to introduce redundancy into the task execution processes. A large emphasis on redundancy as a safety mechanism has been criticised by organisation scientists (Reiman & Rollenhagen 2011). One of the risks of linear thinking and overemphasis of redundant means to prevent harm from actualising is that the interaction of the added practices and requirements creates more complexity and contributes to the system's opaqueness – which is often not taken into account (Dekker 2011, Perrow 1999). Still, the interviews in plant C suggested that the type of redundancy introduced by, e.g. *Peer Checking* in general were perceived to be useful, and many of the interviewees readily provided examples on how *Peer Checking* had helped prevent unwanted events (see, e.g. Skjerve & Axelsson 2014).

A concern, which is often raised in discussions of error reduction approaches, is that they aim at reducing *performance variability*. On the one hand, it is understandable that nuclear industry organisations aim to increase predictability of the performance to fulfil the required safety standards. On the other hand, many modern safety scientists claim that performance variability is a necessity to maintain safety of complex systems (e.g., Hollnagel 2009, Dekker 2011), and that organisations should be careful not to dampen that kind of variability of human performance that allows them to identify and respond to unexpected situations in an innovative way.

This issue of how HU tools achieve their purpose is further complicated by the fact that HU tools are not identical: Some HU tools prescribe performance in details, others aim at catching active errors others again focus on experience sharing, and others at sensitizing personnel to notice unexpected events. This implies, e.g., that not all HU tools can be readily perceived as introducing redundancy in work processes, e.g. *Operational Experience* servers a different suppose.

Figure 1. The HU tools applied at plant C structured depending on their level of performance prescription (Skjerve & Axelsson 2014, 6).

Similarly, it implies that not all HU tools can be perceived as reducing performance variability, e.g., *Questioning Attitude* may rather been seen as adding to performance variability.

We believe it is essential that plant management are clear about why HU tools are introduced and aware that the tools may work differently. This will promote alignment between leaders and personnel with respect to when and how the tools should be used.

3.2 What have the measurable benefits of human performance tools been so far in the plants?

The measurable benefits of HU tools seem to be only rarely assessed at nuclear power plants. In the International survey, one respondent reported that error reduction had been achieved due to a Human performance programme. He stated that, thanks to the introduction of HU tools:

> *"For the company, the human error rate is divided by 4."*

Another respondent in the International survey reported the following effects:

> *"With the formal introduction of HU tools the Industrial Safety Accident Rate decreased significantly and Capacity Factor increased significantly."*

During the interviews carried out in the Nordic plants B and C, it was easy to obtain descriptive examples of how HU tools in specific situations had contributed to prevent negative impacts on occupational safety and/or had contributed to efficiency, e.g. by preventing an unplanned shut-down. However, overall measurable benefits of introducing HU tools seemed rarely to be calculated. It sometimes appeared as if the belief that a positive relationship exists between the practices implied by the HU tools and error protection was so strong that positive effects of using HU tools were taken granted.

The respondents of the international survey were asked to report the plant availability rate and number of scrams. We could not identify statistically significant differences on those indicators between the organisations that had utilised HU tools for long period (which could be assumed to have good performance since HU tools are routinely used) and those that introduced them recently (where the results of the tools could be assumed to have realised only to small degree). It may be that the small variance in the indicators explains this result.

From a measurement perspective, there are, however, also many challenges associated with obtaining a reliable measure of the effects of implementing HU tools: An assessment would need to be based on data obtained over a certain period of time. In this period, changes may often happen, e.g. in staffing, instructions, tools and/or equipment, etc. For this reason, it can be challenging to distil the exact effect on human performance caused by the HU tools. Another complicating factor can be that some of the HU tools introduced have been applied in the plant as common work practices, prior to being introduced as HU tools, which may reduce the difference uncovered in prior- and post assessments to measure the effects of implementing HU tools. Moreover, there be 'unintended' benefits from using HU tools, e.g. positive impacts, which are not the basis for implementing the tools, and thus not addressed in assessments.

The only attempt to calculate the economic impacts of HU tools introduction – or more generally a Human performance program were HU tools were a part – was performed by Axelsson (2012, 2013) (cf. Skjerve and Axelsson 2014). Based upon plant event history, it was assessed that 63 % of production losses would have been possible to prevent, given the resources and competencies within the organisation. It was then assumed that a fully effective human performance (error-preventing) and CAP (operating experience) system have the potential to address 20 % of the 63 % preventable losses. Axelsson identified the following effects: Concerning *occupational accidents* losses, the annual cost savings following the introduction of a Human performance program could be around 500000€ (and mainly related to outage periods with 1000 staff). Concerning *production losses*, the *annual* cost savings were estimated to be around 3000000€. The total financial investment in the Human performance program's roll-out and basic training during the initial two years 2007-2008 was estimated to approximately 500000€, and 100000€ each following year. Given these figures, introducing the Human performance program, and assuming it fully operational and effective, provides 35 times in return on the investment (ROI) every single year after the initial implementation phase (3500000€ ÷ 100000€ = 35). Not included in this case is an actual production loss of 9 months in 2011, almost entirely related to Human performance and at a cost of 250 000000 €. Assuming a probability for one such event per 80 reactor year in a plant comprising of four reactors, will increase the annual cost savings with another 3000000€.

One question of concern is the extent to which calculating the measureable benefits of introducing HU tool in one plant (regardless of how the calculation is done) can be applied as reference in other plants. The effects of HU tools would seem to be markedly impacted by a range of organisational and cultures factors, which will be discusses in the following section, and unless two plants are relatively similar with respect to these issues, the results may not be useful.

3.3 How do maintenance personnel perceive the application and effects of human performance tools?

3.3.1 Overall maintenance personnel have a positive view on HU tools

The Nordic plants B and C had several years of experience with using HU tools, and maintenance personnel in these plants overall had fairly positive view on HU tools. In plant B, the majority of the maintenance personnel agreed that HU tools improved plant safety, more precisely, 72% of the personnel in I&C and electrical maintenance and 90% of the personnel in mechanical maintenance. In plant C, more than 74% of the questionnaire respondents fully or partly agreed in the statement that "HU tools contribute to promote plant safety". In addition, 88% of the questionnaire respondents at plant C found that HU tools were generally useful and well integrated into their work processes. However, there were also some reserved and even very critical opinions on the tools and the way they had been introduced at the plants.

The above results may be a little surprising from a cultural perspective. Overall, corporate culture as well as national culture can be expected to affect maintenance personnel's attitude towards safety management approaches and workplace development (see e.g. Kim & McLean 2014). In Nordic countries corporate culture can be characterised as democratic: the power distance is low (there is little hierarchy and employees are independent), employees participate in decision making concerning organisational development, and especially in Sweden, managers strive for consensus with their subordinates rather than use their formal power (Hofstede 2001, Grenness 2003). In this kind of cultural environment safety management approaches which set behavioural expectations and controls to individual's ways of conducting their everyday work are not necessarily easy to implement. For example Zimmerman et al. (2011) reported that in a study concerning aviation industry safety approaches the Northern European respondents were more critical towards traditional safety approaches (e.g. human error focused approaches) than the rest of the respondents from all over the world. Human performance programmes with tools that define how one should talk (*Phonetic Alphabets and Three-Way Communication*) or tools that involve close supervision of behaviours and actions (*Peer Checking, Task Observations*) may seem alien to Nordic work cultures. For this reason, it might be expected that maintenance personnel in the Nordic counties would have had a negative view on HU tools. Actually, some respondents were uncomfortable with *Peer Checking* and *Task Observations* as they were seen as questioning one's expertise, further *Three-Way Communication* was seen as naïve by some respondents.

One factor that may have contributed to Nordic maintenance personnel's' overall positive views on HU tools was that many of the work practices implied by the HU tools had already been applied in the plants for several years before they were (re-)introduced as a part of the general HU program as HU tools. It would seem then that the behavioural expectations and controls implied by the HU tools had already passed the test of time as useful work practices.

When considering the individual HU tools, maintenance personnel generally regarded HU tools that were integrated into their work processes (such as e.g. *Pre-Job Briefings*), as the most important for ensuring safety – as opposed to e.g. *Task Observation*. Overall, *Pre-Job Briefing* was perceived to be the most useful of the HU tools in both of the Nordic plants. It was also the only tool, which all respondents in the International survey, reported that they used (see Appendix A). The benefits of *Pre-Job Briefing* were associated with coordination and preparation for complex and unfamiliar work tasks jointly performed by a group of people.

3.3.2 **Newcomers' and old-timers' perspectives on HU tools**

Even though maintenance personnel overall held a fairly positive view towards HU tools, there seemed to be a distinction between the views of newcomers and old-timers.

Newcomers seemed to have the most positive perception of HU tools. Partially this might reflect the generic change among the younger generation in attitudes towards safety or "soft issues" such a human errors, as some of the interviewees suspected (see also Loughlin & Julian 2001). However, the interviews suggested that newcomers' positive perception could be associated with their wish to develop a professional identify as a “maintenance professional”. They seemed to perceive HU tools as concrete means to communicate how work was to be carried out in the organisation, and thus as tools that promoted their ability to work and act *as professionals*. For the old-timers, on the other hand, the formalisation of existing work practices as HU tools might be viewed with more scepticism. The reason was that a formalisation implied that when work practices were transformed into HU tools their use became a means of managerial control, which managers could sanction personnel for *not* following (e.g. telling the staff member that he should use the HU tools). After the formalisation, old-timers might, e.g., feel forced to use HU tools also in situations where they did not see the need for doing so. Thus, for old-timers, the introduction of HU tool may be perceived of reducing the autonomy associated with task performance, and thus their ability to exercise professional judgements.

3.3.3 **Organisational factors impacting maintenance personnel views on the effectiveness of HU tools**

The case studies indicated that maintenance personnel’s perception of HU tools were influenced more by factors, which had to do with the context in which the HU tools were applied, rather than with the specific characteristics of the HU tools as such. The interviewees emphasised that HU tools should not be used excessively: the tasks in which they are used should be carefully selected and the tools should not be rigid but be scalable to avoid overdoing error reduction in simple tasks. The cases where the interviewees expressed criticism towards HU tools usually related to situations where the tools were required to be used in tasks which were considered routine, frequent, simple, not error prone or safety critical. In plant C, the factors, which maintenance personnel themselves perceived to impact the extent to which they would use HU tools are summarised in Skjerve and Axelsson (2014). Except for one, i.e. the rigidity of the HU tool, all of these factors are organisational or situation-specific in nature.

Based on the insights gained from the study, we suggest that at least three factors impact the (perceived) effectiveness of HU tools use in maintenance work in addition to type of tasks (routine vs. complex, safety significant vs. non-safety critical, new vs. frequent task) and the rigidity of the HU tool: (1) that using the tools *makes sense* to the workers, (2) *group climate*, and (3) *possibility to use* the tools e.g. that there are resources available. Leadership affects all of these to a significant degree. These three issues are depicted in Figure 2 and will be discussed below.

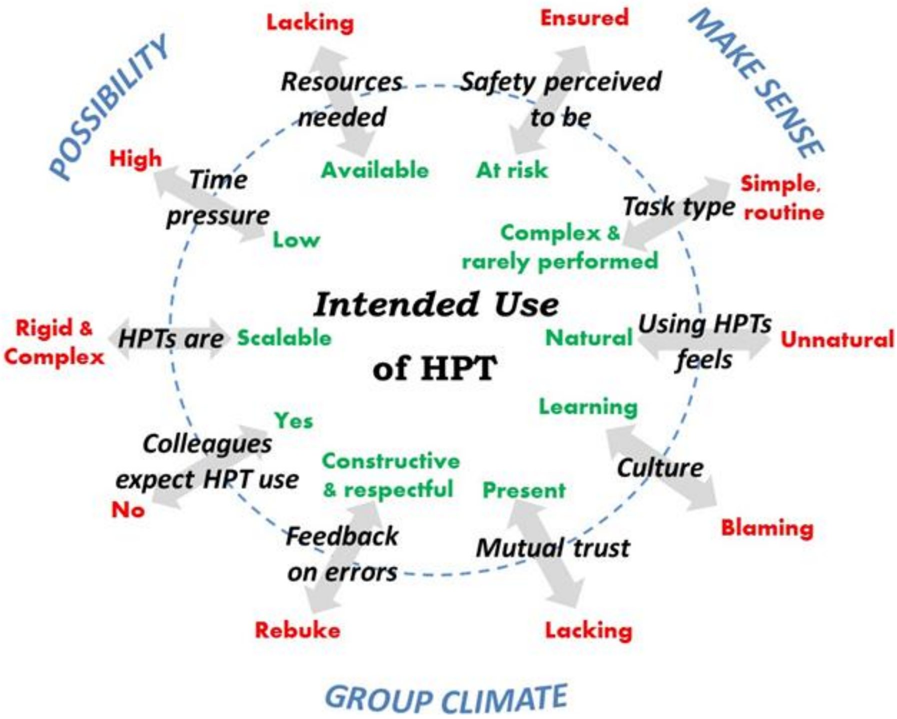

Figure 2. Factors affecting the likelihood that HU tools will be used as intended based on an analysis of the most typical responses provided by maintenance personnel (adopted from Skjerve and Axelsson 2014, 22). Note: In the figure 'HPT' = HU tools.

HU tools must make sense

The study shows that HU tools could be accepted if it is understood what the goals for implementing them are, and if the goals are agreed with. It seems that the tools were accepted if they were perceived as tools to *support* safe and efficient work processes, rather than e.g. as tools control and discipline personnel. The organisation needs to pay special attention to avoiding 'blaming' workers for system problems. Thus, if a company suspects that it has a 'Human Performance problem', it should first ensure that fundamental issues related to staffing, equipment, work processes and supervisory activities have been well addressed, rather than addressing system problems by implementing HU tools.

During the study, it was seen as useful to distinguish between simply 'use of HU tools' and 'use of HU tools as *intended'* (Skjerve and Axelsson 2014). The concept *intended use* was applied to emphasise that HU tools should be used *attentively* and *resiliently, i.e. robust yet adaptively,* with the aim of *fulfilling their specific functions.* Overall, using HU tools should not be blind execution of the required behaviours. It was found that if leaders focused too much on ensuring that maintenance personnel *used* HU tools, it could lead to *mechanical execution* of the behaviours implied by the HU tools. Still, mechanical execution would not guarantee that the tools were used as intended, i.e. in ways to promote safety. A person might, e.g., repeat back a message, without understanding what it meant when using *Three-Way Communication*. HU tools should *not* been seen as a means in themselves. This was nicely expressed by one of the respondents in the international survey:

> *"The use of tools does not guarantee fail safe operation. The people have to know, how to use the tools correctly. Over reliance on the tools might cause problems. The main tool is always "Use Your Brain".*

The study indicated that if the use of HU tools is motivated with reference to satisfying external (e.g. peer groups) or managerial pressures to simply use the tools there is a risk that the respect for the HU tools may start to erode. This could happen, e.g. when managers require maintenance personnel to apply e.g. *Pre-Job Briefing* a particular number of times during outage to obtain their bonuses. Even if the actual agenda is that maintenance workers should practice use of this HU tool, we recommend that this type of practices should preferably be avoided.

Group climate

Another factor that surfaced again and again was the importance of *group climate* for HU tools use, and in particular the level of trust between maintenance personnel. This factor was also associated with the importance of ensuring that HU tool use was not used as a basis for blaming personnel, if things went wrong. In the questionnaire surveys in the Nordic plants, it was found that the simple act of being checked by someone – as in *Peer Checking* – could be perceived by the person being checked as *mistrust* with respect to his/her professional skills (Skjerve & Axelsson 2014). Similar issues were raised in relation to e.g. *Task Observation*. On respondent stated:

> *"If you are observed too often, it can be disruptive and it can be perceived as a lack of confidence."*

It was also emphasised that if a person (peer) asks *too many questions* to his/her colleagues, the person would get the reputation that he does not trust the professional judgements of his colleagues.

Another important issue in relation to this was also *how* feedback (from the peer) was provided. This was a factor that we associated with the pedagogical competence of the person providing feedback. One respondent stated:

> *"Feedback following Peer Checking can be perceived as rebuke and supervision, if done in the wrong way."*

Another emphasised that critique should be based on a true understanding of the task and the contextual factors impacting task performance:

> *"It is not meaningful if an observer only looks for shortcomings and fails to discuss the work conditions."*

Overall, the study indicated that characteristics of the organisational culture may markedly impact maintenance personnel's' attitudes to and use of HU tools. National culture, on the other hand, affects the organisational culture.

Cultural sensitivity of HU tools came up in the Nordic case studies. It was suspected that the Anglo-American organisations use HU tools in a much disciplined manner and that would not be suitable for Nordic organisations. The autonomy of the workers and supervisors to tailor the tools and decide on the situations where they should be used was emphasised. The international survey results also showed some indicative cultural differences in perceptions towards HU tools. Concerns that using HU tools would dampen employee self-initiative and situational judgement were mainly raised by respondents from other European countries than UK.

There are differences between Finnish and Swedish culture and management. Finnish managers are described as being more production and task-oriented whereas Swedes are more human oriented, "feminine" in Hofstede's terms (Lämsä 2010, Hofstede 2001). Lämsä (ibid) claims that: *"one of the special features of Finnish management is impatience. Solving problems and handling in the chaotic circumstances is normal for the Finns. Often the task will begin although exact plans have not yet been fully performed".* For this reason, it could be expected that Swedish and Finnish maintenance personnel might use HU tools differently and/or that different factors might impact their judgement of HU tools use. The study found out that in Finland the power companies have been more reserved towards introducing a formal HU programme than in Sweden. In one of the companies they had introduced 5 tools and the other company was still considering their strategy towards HU programmes, whereas in Sweden the implementation of the HU programme begun earlier and they have selected a broader range of tools to be introduced.

<u>Possibility to use the tools</u>

Using HU tools takes time. This topic was brought up one way or the other by the majority of the participants in the Nordic plants and in the international survey. The most common line of reasoning can be summarised as follows: When managers require that maintenance personnel should use HU tools, they require use of 'add on' practices, i.e. practices that are not essential for task execution. For this reason, it is essential that they recognise that the pace of work will be reduced. One of the examples provided was organising of *Pre-Job Briefings*: Getting all the relevant people in place may take time. For example control room staff cannot participate to *Pre-Job Briefings* during the shift turnover, and thus maintenance personnel have to wait for them. Another example provided was use of the HU tool *Questioning Attitude*: If the work schedule was tight, raising questions might delay the work (further) and were not necessarily welcomed by managers and colleagues. The fact that trade-offs were made in such situations was also exemplified e.g. in the following statement from one maintenance personnel:

> *"It is good to question tasks with reference to safety. Still, sometimes we must make a decision, so that we can move forward with the task."*

In addition to time use of HU tools requires human resources. Most often mentioned example on that was *Peer Checking.* Interviewees reported cases where *Peer Checking* is required for work that is typically done alone. They reported that it is difficult to fulfil the requirement because there simply is not enough personnel to work in pairs.

For HU tools to be able to fulfil their purpose, it seems vital that they become an *integrated part of the work practices of maintenance personnel* in a plant – rather than being seen as add-on to existing task execution processes. How this integration should be achieved may differ between cultures and nations. A respondent in the International survey offered the following solution:

> *"If the Human Performance Programme follows a blueprint, everyone applies the same rigour to error reduction and it becomes part of normal business, it is then a vital ingredient. If it sits outside normal business as a never ending initiative then it can become dependent upon management knowledge, ability, and preference and in some cases feel like a nice to have".*

We believe that a solution focusing on rigidly applying HU tools as suggested in the above quote will not be a successful way forward, at least in Nordic countries, because rigid use of HU tools is no guarantee that safety will be uphold.

3.4 What characterizes successful human performance tools and implementation processes?

In the previous chapter, three factors of vital importance for the effectiveness and thus conditions for successful human performance tools were identified: (1) HU tools must make sense (2) group climate; and (3) possibility to use the tools. In this chapter we will discuss approaches to support these factors – and in particular to build an understanding of *why* to use the tools. The *why* is fundamental for a successful implementation, when the aim is to embed the HU tools as something that people find useful and natural in everyday work settings.

The case studies gave strong evidence that the application of HU tools should make sense, rather than to be rigorously applied at all tasks. Instead, they need to be scalable given the characteristics of the task. This is not in conflict with the guidelines provided by DOE, INPO and WANO. They emphasize that HU tools should be applied in respect to the characteristics of, and safety significance in, the task at hand. This approach needs to be supported by training and managed as the tools are used. A good opportunity to continually support this approach is in Pre-Job Briefings or Task Previews. Rather than viewing safety as a well-defined and safe performance as something easily specified, safety can be viewed as a dynamic state subject for *change pressure* (Reiman & Oedewald 2007), or as Hollnagel expresses it, capability to succeed under varying conditions, which requires *performance variability* (Hollnagel 2012).

This suggests that it is the people organized around a specific task that has to define the suitable application of HU-tools to support the task performance. Also, considering some less descriptive HU tools as e.g. *Questioning Attitude* (see Figure 1), much is actually left to individual judgement. Thus it becomes essential to train and prepare the personnel for this dynamic approach to safety.

Experiences from plant C may serve as an example of a long-term implementation of HU tools. HU tools were not necessarily introduced the most structured way; rather lessons were learned en route by staff members and leaders. Hence, based on those lessons, we suggest a progressive approach to implementation to gradually develop knowledge and understanding. It should be a shared learning process among staff members, their leaders and also human performance managers; it should constitute organisational learning. The process would involve open communication, knowledge build-up (in specific about the HU-tools), workshops on the prerequisites and the feasibility of the tools (with each sub-team), comprehensive training, and reflective follow-up workshops on approaches. Furthermore, the process would include open discussions on attitudes and conceptions to proactive safety work (in both team and individual contexts). Following is brief descriptions on each of these towards a successful HU tools implementation.

3.4.1 **Introductive communication**

In the plant C there was little pre-communication of the human performance programme to the personnel, other than to the plant department management lead teams. The roll-out of information concerning the initial training, a web-based e-learning, was cascaded top-down through the line organisation.

Step #1: Develop a communication plan which supports an understanding of the plant's rationale for introducing a human performance programme. The rationale need to explain e.g. why to formalize some of the existing work practices and to emphasize that human error reduction is not an aim as such. Instead, the focus should be directed towards a systemic approach to safety and HU-tools as one of the means to support safe work.

3.4.2 **Knowledge build-up**

After the first attempt at plant C to introduce HU tools by the so called "HU lanyard cards" to hang around one's neck, a special HU training on the tools were developed as e-learning and rolled out via the intranet and global internet. The e-learning was rather concrete, giving information on *why, when* and *how* to use each type of HU tools. The material included video examples e.g. from every-day examples such as restaurant visits. Tests followed each chapter and final test was introduced in the end. The format of the training had a threefold goal: to offer a user-oriented type of learning, stimulating the students' curiosity, and to support the understanding of the rationale for HU tools. Following the training a special brochure to carry, covering the basics, was distributed. It appears that this format of training was both useful and effective in terms of an initial knowledge-building when large number of personnel and contractors needs to be reached.

Step #2: Facilitate knowledge on basic premises concerning the HU tools, i.e. *how* the tools work, and thus, what they intend to support, which also leads to *when* to use them. This step continues supporting the theme of *why* to use the HU tools as *intended*.

3.4.3 **Prerequisites and feasibility**

Later, during the HU roll-out at plant C a series of workshops were launched. The workshops had a specific theme: ensuring the feasibility of HU tools in each sub-team. The workshops aimed at discussions and reflections, and emphasised that there is no right or wrong answers. The idea was to allow each team to form their own approach on *why, when* and *how* to make use of HU tools in their own every-day work settings. Team leaders and supervisors were encouraged to promote open discussions, and to conclude the teams' viewpoints as well as to share their own.

Step #3: Support the organisation's ability to find sensible ways of using HU tools by inviting the personnel to open discussions on pros and cons in relation to their local settings. It may be useful to utilise case examples from the plant and have discussions on approaches that potentially could have changed the course of the events. This step will engage personnel and promote a self-driven approach towards embedding the HU tools in their work practices, which will promote a feeling of ownership to the tools. It is important that team leaders and supervisors support openness and embrace different views. There is a need to follow-up this, see step #5.

3.4.4 **Hands-on self-inductive learning**

For a considerable time, there were limited opportunities for hands-on HU-training at plant C. However, operators receive training in some of the HU tools while conducting their periodic simulator training. Maintenance workers had just one-time training in a specific nuclear professionalism course. Contractors received no training other than to a limited extent in their induction training (e-learning). The plant has recently developed a HU-simulator.

Step #4: Develop a training programme for targeted groups including both plant staff and contractors. Provide hands-on training in a HU-simulator (applicable mock-ups) to target nuclear, plant safety and personnel safety. The aim is to demonstrate the use of the tools and let people try HU tools. It is essential to avoid inducting by one-way-communication, but rather to stimulate open discussions and reflections. Effective learning is enhanced by self-imposed testing, learning and adaptation. Preferably, the training is facilitated by trained supervisors, team leaders and managers in order to stimulate real-life dialogue on safety.

3.4.5 **Follow-up on approaches, attitudes and conceptions**

Another series of workshops on attitudes and behaviours towards safety in everyday civil life, as well as in work-life, was arranged. Participants discussed typical behaviours in e.g. traffic, domestic and professional life, with respect to a generic scale: pathological, calculative, reactive, proactive, or generative. Then they proceeded discussing the same behavioural patterns in professional life, themselves providing typical examples. In the final step, participants reflected upon their personal and specific approach need for taking the next step up the scale. The overall aim at the plant C was to move from reactive to proactive approaches, however the workshops gave the insight that the organisation in reality tend to move up and down the scale pending on contextual priorities. Hence, an important outcome from such work may be an increased self-awareness, and incentive for being mindful and more wary.

Step #5: Organise follow-up workshops on safety matters that need attention. Open discussion formats may provide the most effective outcomes in terms of elevating actual and desired behaviours. Mindful facilitation is essential to provide for openness amongst participants. It may be effective to relate attitudes and behaviours to everyday civil life and work situations, and to discuss the preconditions for professional safety practises and to put this into a context of the desirable safety goals. It may prove that certain pre-conditions for safe work performance are not well provided for, hence they should be addressed in order to support the personnel towards mindful safety practises.

3.5 What aspects of maintenance work are most effectively met by HU tools, and what could be solved by other means?

If an organisation wishes to apply HU tools to reduce human errors and related safety issues they need to carefully consider the following aspects. As discussed in section 3.1, there are many potential types of errors and error mechanisms associated with maintenance work. For the error reduction techniques to be effective the organisation should first understand what kind of errors they consider likely and problematic and then analyse what are the tools that could help in mitigating those error mechanisms in the most critical cases. It seems fair to suggest that tasks which will have direct plant safety impacts should be prioritised. Further, if there are repeating issues with certain types of tasks, it is an indication that they need to be studied carefully. In these cases HU tools might be a part of the solution. In the case organisations opinions were expressed that HU tools should be used mainly in tasks that are new or infrequent since more frequent tasks involve less risk for errors. That is not necessarily the case; the error types and mechanisms may change as workers get more use to the task. Frequent or routine tasks may be still safety critical and thus important to address when considering HU tools.

Organisations should understand if unwanted outcomes of task execution are more effectively solved by improving the working conditions, tools or modernising the technical components. HU tools should not be used as a means to avoid attending to the system problems. There may be also fairly clear error traps, such as similar valves or similar doors side by side with poor markings. Rather than using HU tools in preventing workers from mistaking on the door the organisations should remove the error trap. Most likely all operating units have gradually improved their working conditions and removed error traps as the operating experiences have cumulated. However, it may be more effective to do that kind of analysis and corrective actions before deciding where to utilise HU tools.

The interviewees were inquired what other means than HU tools are used or could be used to support safe and reliable, or error free, human performance. The responses indicate that the maintenance employees felt that organisations have already done a lot to ensure the reliability of the work performance. Instructions, work permit system, personnel selection, training and using modern tools e.g. automatic readers and other hand held devices, were seen as commonly applied means to reduce human errors.

Supervisory activity was also seen as crucial error reduction possibility. The interviewees described how supervisors hand-pick the workers for certain tricky tasks, take care of workers' work load and monitor e.g. the fitness for duty issues. The maintenance foremen explained how they aim at verifying that the technicians have understood the assignment. Rather than organising a full scale *Pre-Job Briefing* or requiring the use of *Three-Way Communication* principles the foremen considerately 'interviewed' the worker to detect if the understanding was accurate.

Higher order organisational factors, such as values and norms do affect the performance of individuals. It is important that the priorities are as clear as possible. This helps the individuals to balance the sometimes conflicting goals such as efficiency vs. thoroughness or conservative decisions vs. continuation of production in a manner that is mutually agreed upon. Even if in the course of the work process the worker needs to do a sacrificing decision, e.g. to delay some important tasks in order to be able to fix an acute equipment failure, it doesn't lead to failure if the decision is agreed upon and the organisation can mitigate its effects.

The last theme to be mentioned here is organisational learning. Sharing knowledge on e.g. tricky work tasks and means for coping with them helps in avoiding problems in those tasks. This is one of the goals of *Pre-Job Briefing* but there are multiple ways in which organisational learning takes place. Often the knowledge transfer takes place informally and without any specific aim, such as error reduction. The power of gradual development of collective expertise and tacit norms should not be forgotten, although the nuclear industry culture values 'tools and programmes'. Organisations should provide forums for such knowledge transfer, including also the subcontractors. The other side of the coin is that many of the experiences which could be useful for the colleagues in the future are perceived as mundane and are thus not shared.

4. Recommendations for the nuclear industry concerning the Human performance programmes

The recommendations provided in this section are built on the authors' expert judgements based on the insights gained during the course of the study. They may be regarded as *lessons learned*.

Recommendations on when to use and when not to use HU tools

- An organisation should have a clear understanding of the *overall purpose(s)* it intends to fulfil with HU tools: The aim of the HU programme and HU tools should be clear because it determines *what* tools to be used and *when* and *how* they should be used.

    - The study shows that HU tools may serve a range of different purposes: plant safety, occupational safety, on-the-job learning, and/or effectiveness.

    - Consider that preventing human errors is not a sensible purpose in itself. The organisations cannot and should not aim at dampening *all the variability* of human actions. The variability which sometimes results in unwanted outcomes is also a necessity for safe operations because it allows e.g. efficiency and quick reactions.

    - Determine indicators which may help you in monitoring the impacts of your HU programme.

- HU tools should *be* introduced to *support* personnel rather than control their activity.

- HU tools should *not* be introduced to "fix" 'behavioural problems.'

    - If an organisation has fundamental problems associated with, e.g., communication issues, poor work conditions, lack of training, poor procedures, HU tools will not constitute a "quick fix". Rather, these types of problems should be addressed at their source.

    - HU tools should not be used as means for disciplining personnel in a response to 'behavioural problems': they should not be means for blaming staff.

- Be aware that the work practices implied by HU tools may already be a part of - or be highly similar to -work practises, which is currently used in the plant. Consider if it is useful to formalise the current practices as HU tools: What are the benefits and what the potential costs (e.g. negative impacts on existing work patterns).

- HU tools should be introduced only if the rationale for the HU programme is clearly communicated to the organisation and shared by its members.

    - It is of key importance to ensure management buy-in: Educate management and provide managers with whatever preconditions they need (tools, time, systems, etc.) to support HU tools use.

Recommendations regarding the type of HU tools that should be used in maintenance work

- When an organisation has clarified the purpose(s) that the HU tools should serve (see recommendations above), it may consider the suitability of the numerous HU tools described by e.g. DOE (2009b) or similar documents, in light of the characteristics of the local organisational context. In this process, a *systemic view* on risk and safety should serve as basis.

  - When selecting HU tools, address the relationship between existing work practices and the practices implied by the tools to promote that use of the HU tools will be well-integrated in or adapted to existing work practices.

- Be aware that HU tools involve different levels of performance prescription: Procedure Use is a highly prescriptive HU tool, as opposed to Questioning Attitude. Highly prescriptive tools should be associated with highly predictive performance requirements only.

- When selecting HU tools, ensure that it is possible to provide staff members with the necessary (additional) time and human resources it will or may require to use them. This is necessary to avoid unintended side effects such as increasing backlogs of work tasks.

- Also note that some HU tools in addition to safety purpose, may serve a broader on-the-job education purpose of transfer to experience between personnel, e.g. Peer Checking and Task Observation.

Recommendations on how to use HU tools

- Personnel need freedom to exercise judgements about when and how to use HU tools. This is necessary to support that HU tools will be used as intended.

  - It is important that managers understand how HU tools are intended to be used.

  - Personnel needs to understand the type of risks the various HU tools are intended to address.

- HU tools should *not* be used instrumentally, i.e., rigorously and/or for self-serving purposes.

    - Frequent and instrumental use of HU tools may potentially contribute to establish a false sense of safety.

    - Avoid motivating use of HU tools as a means of obtaining other aims than they are intended to fulfil. If HU tools used to promote safety are required to be used for other purposes (e.g. to achieve bonuses or legitimation), the regard for HU tools to fulfil their original purpose may be reduced.

Recommendations on how to introduce HU tools

- Use a systematic approach when introducing HU tools (see an example on one such approach in Figure 3).

- When introducing HU tools, carefully consider the names of the HU tools. Adjust the names if necessary to make sure these are intuitively understood and accepted by personnel.

- Overall, the introduction of a HU programme, and as a part of it HU tools, should incorporate the following steps:

    - Analysis of the actual needs.

    - Ensure that HU tools are well integrated into the overall Human performance program, ensuring alignment with other organisational processes, e.g. work management.

    - Definition of what HU tools to be introduced and their specific purpose(s).

        - Document the ways and conditions the HU tool may be used in the local context.

    - Identification of targeted groups: technicians, engineers, managers, contractors, etc.

- Developing of a method for implementation the HU program (and HU tools).
    - Training – potentially a qualification program.
        - Introductory training: to provide personnel with the insights on the purpose of using HU tools and competence in using the tools.
            - Be aware that introduction of HU tools may also require training aimed at un-learning older practices.
        - Follow-up on the use of HU tools in the everyday setting.
        - Refresher training.
    - Follow-up and the implementation process using, e.g., trending, self-assessment and/or analysis of selected indicators (feedback from the field), and adjust the course if needed.

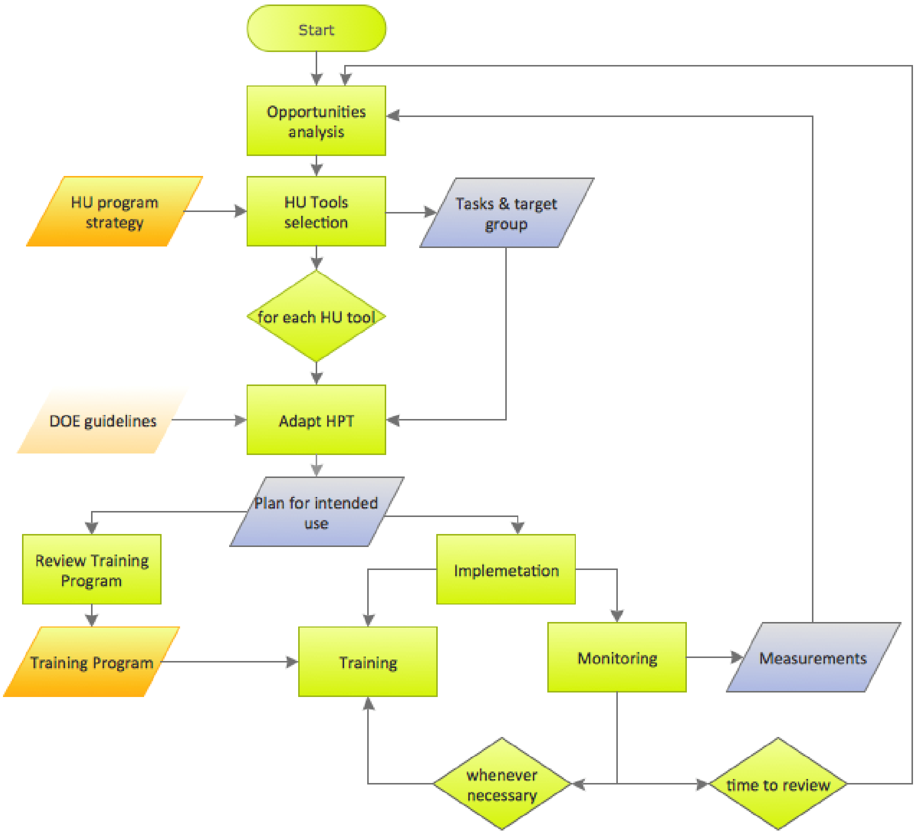

Figure 3. A diagram depicting the main stages of a succesfull implementation of HU tools.

5. Conclusion

The study aimed at shedding light on rationale and impacts of human performance programmes in nuclear industry. More specifically it focused on human performance tools applied in maintenance work. The study addressed five research questions, based on data obtained in three case studies in Nordic nuclear power plants and an international survey.

First: *What are the expected benefits of human performance tools applied in nuclear power plant maintenance?* The beneficial effects stated by the majority of participants in the study are to prevent and reduce human errors and related unwanted events. HU tools were seen to promote both occupational and plant safety this way. However, especially during the interviews and the questionnaire survey at the Nordic plants it was uncovered that HU tools might also be introduced for more reasons than direct safety concerns alone, e.g. to promote effectiveness, ensure business performance and to transform working culture. Often the initiative to launch a human performance programme and to implement HU tools came from peer groups, e.g. during peer reviews.

Second: *What have the measurable benefits of human performance tools been so far in the plants (e.g. reduced number of failures, reportable licensee event reports, human errors*)? Even though plants may follow-up on HU tools use in different often qualitative ways, they rarely systematically measure if the expected benefits have actualised. We received only anecdotal evidence that some organisations had measurable improvements in their industrial safety accident rates, capacity factor and rework rate. One reason might be that it is simply difficult to distinguish between the impacts of HU tools and other factors affecting the organisation at the same time. Another is that it is essentially difficult to extract statistically significant data from nuclear safety measures, e.g. number of INES classified events, or number of scrams, since the frequency of these events is typically low. Thirdly, it seems that some power plant organisations have not specified any clear goals for the human performance programme and thus they have not specified what kind of measurable effects they would expect from it.

Third: *How do maintenance personnel perceive the application and effects of human performance tools?* Most maintenance personnel have positive attitude to HU tools. They found that the tools were fairly well integrated in their work practices, and supported their performance as well task effectiveness. Especially the newcomers held a positive attitude to HU tools. However, a minor group of maintenance personnel held highly negative attitudes towards HU tools. In general, they feel that HU tools were superfluous, time consuming, and means to control (blame) the workers. Overall, the maintenance personnel emphasised that HU tools need to be scalable to the work task and the working groups need to have some autonomy to decide when each of the tools is used.

Fourth: *What characterizes successful human performance tools and implementation processes?* The HU program should be aligned with other organisational processes, and the necessary pre-conditions should be established, e.g., management buy-in, work processes allowing time for using HU tools, a no-blaming culture. The introduction of HU tools need to ensure that maintenance personnel know *why*, *how* and *when* they should use the tools. It should be practical in nature, and address both learning of new work practices and un-learning of old work practices. Learning should be a two-way experience: the instructors should use feedback from the trainees to improve the HU program.

Fifth: *What aspects of maintenance work are most effectively met by use of human performance tools, and what could be solved by other socio-technical means?* HU tools should never be the automatic response to performance issues, such as quality issues in task execution or procedures not being followed. It is necessary to ensure that one addresses the underlying factors that cause the issues (e.g. working conditions, competence issues). When HU tools are used as human error reduction techniques, the organisation should understand that there exist different error types and error mechanisms that require carefully selected HU tools. Also the various task characteristics need to be considered, such as safetycriticality of the work task, experienced problems in the past and the frequency of the task execution.

The results obtained from the study partially resonate with the criticism pointed at error or individual focused safety approaches. In maintenance context HU tools were reported to require extra time and resources that were not always provided for, which may create unwanted side effects on the performance in the end. Also indications that HU tools sometimes bring along a more mechanistic way of working and dampen workers' self-initiative was seen. Some experiences of blaming atmosphere were also reported. However, the study indicate that in many organisations human performance programme is to a large degree a title given for working practices most of which have for long been embedded in the maintenance work practices. They have not been originally developed from human error prevention point of view. Rather, they are institutionalised professional practices that aim for good quality work. As the Nordic case studies show the recent initiatives to promote the tools as part of human performance programme has created some confusion among the workers.

Overall HU tools, even though they come in many forms and shapes, with a few exceptions (such as procedures) are essentially plain work practices. If the work practices are used as requirements and their motive is perceived to control human performance, they will most likely become instrumental to the workers and they will associated with blaming and mistrust. If, on the other hand, the tools are used as work practices, which are recommended but not constituting rules, they may have a good impact in supporting safe work. A further key factor impacting the effect is the availability of organisational support (e.g. possibility for supervising each other, time to arrange meetings, time to give feedback). In order to maximise the positive safety impacts from HU tools they should be tailored to the context and aligned with existing work processes.

The study has a set of inherent characteristics that may limit the generalizability of the results beyond the Nordic countries. This was a consequence of the selected research approach: the major part of the data collection was carried out in three case studies, which all targeted Nordic nuclear power plants. Thus, the results might be biased by influences from Nordic regulations and culture.[1] Moreover the two case-study plants, in which HU tools were currently applied, both used these tools largely in accordance with the recommendations provided in the present report (see the previous section). This might be an important explanatory factor for the positive views on HU tools that were held by the majority of the maintenance personnel, who took part in these case studies. Had data been obtained from plants, in which HU tools were used to *control* the task performance of maintenance personnel, rather than to *support* the task performance of maintenance personnel, the findings might have been significantly different. The international study was conducted to explore if the results found in the Nordic plants would also be valid from an international perspective. The results obtained from the international survey were not identical with the findings obtained in the Nordic plants, but they largely pointed in the same directions. One limitation of the international survey, however, was that the geographical distribution of the respondents was limited: For example, no respondents from the Asian countries participated. A limitation of the study, overall, was that we might not have succeeded in addressing the issue of measured benefits clearly enough. We failed to ask specifically enough what the indicators showed before, during and after the implementation of the HU tools. It could be that if we had spent more time on this issue during the interviews and if we had posed more questions to this in questionnaire surveys, we would have obtained a better answer to this question.

[1] Typical key characteristics of the Nordic culture often include: low power distance, directness, and consensus in decision making.

APPENDIX 1 International survey

Background and methods

The international survey was a self-administered web questionnaire that was disseminated to nuclear industry human performance experts around the world. The purpose of the survey was to get complementary data to the three Nordic case studies – to have an overview of how human performance programs are implemented elsewhere, what are the underlying motives behind their introduction, and to gather information regarding benefits and disadvantages associated with human performance programs. In addition, success factors and effect indicators were enquired. Finally, another purpose was also to understand whether there are national culture differences, or more specifically, whether HU tools are received better or worse elsewhere in the world than in Nordic countries.

The questionnaire contained both free text fields and multiple choice fields. The free text fields were utilized for open questions regarding the purpose, benefits and disadvantages of human performance programs. In addition, error-reducing techniques prior to human performance programs and other factors that are essential to promoting human factors at nuclear facilities were enquired. The multiple choice questions concerned the drivers of formal introduction of human performance program, human performance tools that the maintenance employees are expected to use, indicators of efficiency and key success factors of implementation. There were also free text fields alongside multiple choice questions that provided the possibility for the respondents to elaborate their answers. In addition, respondent background information was asked.

The questionnaire web link was sent to 1060 individuals who had participated in various human performance seminars and networks. Mailing lists of those forums were utilized to reach experts from different countries. The receivers were instructed to skip or redirect the survey link if they were not involved with nuclear industry and human performance programs.

The survey received valid 95 responses from at least 47 organisations (many of the respondents didn't indicate their organisation) in at least 13 different countries (some of the respondents didn't mention their country). Responses from individuals not working with human performance programs at nuclear facilities were excluded. A total of 67 full responses from individuals that work with human performance programmes in nuclear power plants were utilized in the analysis. The majority of the respondents were from Northern America (Table 1). For many European countries there were one or two responses. The survey therefore comprises mainly of regional and cultural aspects associated with Northern America and European countries. Examples of countries not present in the results are Brazil, China, India, Japan, Pakistan and Russia. In some cases the respondent was in a position that he/she oversaw a large number of facilities and their human performance programmes.

Table 1. The geographical distributions of the international survey respondents

In what country is your organization located?	n
Europe	
Belgium	2
Finland	1
France	2
Hungary	1
Slovenia	2
Spain	2
Sweden	5
Switzerland	1
United Kingdom	5
North America	
Canada	9
United States of America	35
International	1
N/A	1
Total	67

Majority of the respondents (50/67) worked at nuclear power plants, some at corporate fleet level and a few at nuclear service companies. The respondents had various occupational backgrounds and included for example human performance programme leads, safety engineers, supervisors, managers and training professionals. The respondents were very experienced professionals: over two thirds of the respondents had more than 21 years of experience in the nuclear industry. Half of the companies had more than ten years of experience on human performance programs. Only 2 respondents stated less than two years of experience.

The content of human performance programs differed across companies. Of the ten commonly used human performance tools (HU tools) that we specifically covered in the survey, only Pre-Job Briefing was used in all organisations (Figure 1). Other commonly used HU tools were Self Checking and Questioning Attitude.

Independent Verification and Task Observations had most often not been formally implemented. However, they were implemented in nearly 90 % of the cases.

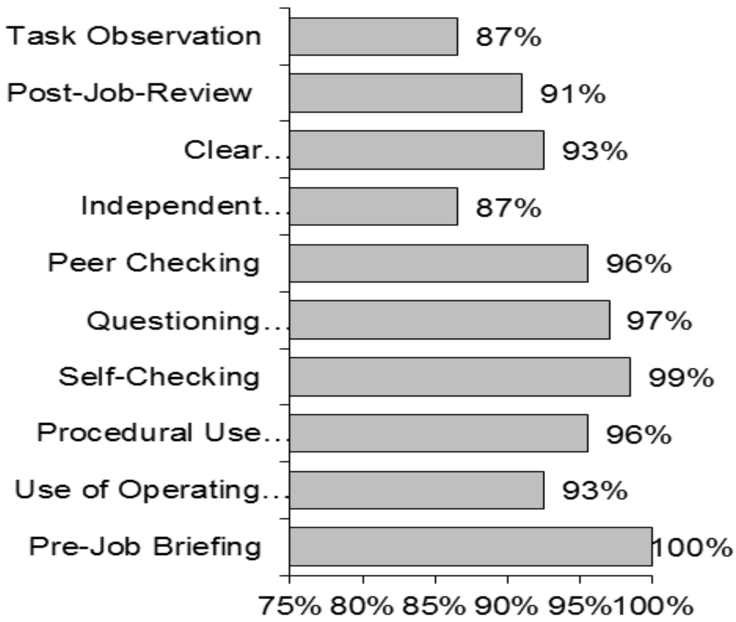

Figure 1. Background information concerning the content of the human performance programs amongst the respondent organisations. The question was "Which of the HU tools are the maintenance employees formally expected to use?"

Results

Purpose and benefits

The survey included questions: "*What do you see as the main purpose of introducing Human Performance Tools in maintenance work?*" and *"In your opinion, what are the benefits of Human performance program/system in nuclear power plants in general?"* The respondents gave similar answers to these questions, although the latter question received richer and more detailed explanations of the connections between the mechanisms and logics of action. The most commonly mentioned purposes and benefits are related to reducing human error, improving or ensuring safety and preventing adverse events. Some answers also pointed out managing safety controls and latent factors.

> *“Safe and reliable operation of the nuclear power plant”*
>
> *“Minimize human error thus improving equipment reliability and plant performance.”*

Safety was referred to as an overall objective and it was not always clear whether respondents meant occupational safety or nuclear safety. Although predominantly human performance programs were associated with safety, business viability and equipment reliability, other improvement targets were commonly mentioned as well. Especially avoiding rework and thus saved time was mentioned frequently. Some respondents brought up working culture or safety culture related improvements, such as improved following of procedures, fostering of appropriate and standard behaviour, and ensuring shared expectations and engagement of workers.

> *“Ensure that maintenance and operating procedures are executed as written”*
>
> *“To get a common understanding of doing work”*

Furthermore, human performance programs were seen as promoting desirable values and norms, or creating awareness of human factors in technical environment. A few respondents suggested that workforce well-being, increased motivation and calmness during working may be related to human performance programmes.

> *“[human performance program] drives the desired behaviours and beliefs of a nuclear safety culture and creates the desired norms.”*

Not many of the respondents attempted to spontaneously provide an explanation of what exactly is the mechanism between the tools and desirable end results. Some respondents, however, explained that the use of human performance tools would lead to a decrease of human errors or latent weaknesses, which in turn would lead to desirable end results such as improved safety or decrease of events. Other respondents pointed out that the effect of human performance tools might not be direct, but rather complementary to other defence mechanisms embedded in the system (e.g. defence-in-depth).

Disadvantages

To the question *"What disadvantages, if any, have you observed after formally introducing Human Performance Tools in maintenance work?"* the respondents brought up two main disadvantages. The most commonly mentioned disadvantage was the extra time required to use HU tools. Another disadvantage was that accurate application of HU tools becomes the goal and that this may distract the focus from the actual task or hinders the understanding of the task. In addition, the risk of developing a climate of blaming shop floor workers came up.

> *"Increasing the burden of paper works that might not be directly related to maintenance works. Increasing the cost and time of maintenance due to the conduct of error-preventing activities (e.g., peer check, independent check)"*
>
> *"Occasionally we find the worker more focused on the HU tool and not on the intent of the work being performed. For example, checking each step of the procedure with a circle/slash and not fully comprehending the intent of the step."*

Some respondents suggested that with proper training and implementation HU tools would quickly become part of regular activities and the disadvantages become less significant. In addition to critical comments regarding HU tools, there was a fairly large group of human performance experts in the international survey (11/67) who held a positive opinion of HU tools and actively reported that human performance programs don't have any disadvantages at all.

Driving factors

The respondents were asked to rate from 1 to 5 to what extent did certain factors affect the decision to introduce HU tools. The highest mean score ($\overline{x} = 3.7$) was found in peer pressure from INPO, WANO and IAEA (Figure 2). Internal safety and business performance initiatives were seen as second most important factors. Regulator expectation was seen as the least significant factor.

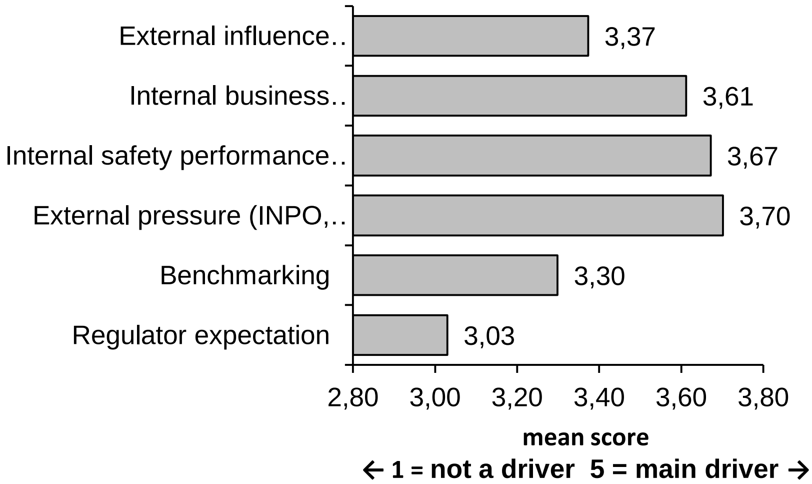

Figure 2. Factors driving the formal introduction of HU tools.

Indicators

The respondents were asked to report which indicators their organisation uses to measure the effects of human performance tools. Both a multiple choice of pre-selected set of indicators and a free text field was provided. The most commonly used quantitative indicators were "number of human performance near misses" and "number of occupational accidents". Rework rate was also often reported. The most popular qualitative indicators used for monitoring the effects of HU tools were work observations. In the free text field the respondents mentioned various error rate metrics and incident or event frequencies. In addition, plant availability and number of reactor or turbine shutdowns were mentioned as measurable effects elsewhere in the survey.

Success factors

The respondents were provided a pre-selected set of key factors and were asked to rank them according to their importance for successful implementation of human performance tools. Median was calculated for the rankings of each factor to provide an overview of the rankings (Figure 3). Management support was considered the most important success factor and was seen as the most important or second most important factor by 2/3rds of the respondents. Human performance training programme, managers observation and coaching, and lessons learned from events were also seen important. Regulator was seen as the least important success factor.

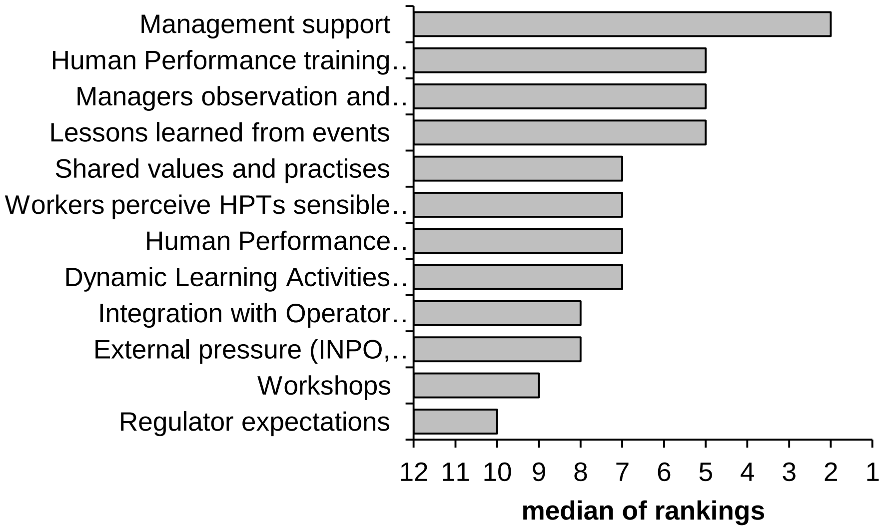

Figure 3. Medians of rankings for key success factors.

National culture differences

European organisations were observed to have less experience on the HU tools than North American organisations. Majority of the respondents from USA or Canada reported that the HU tools were introduced more than 10 years ago. In UK there were many organisations with more than 10 years of experience but also some late adopters of HU tools. In the other European countries most organisations had started the implementation 5-7 years ago.

The reported disadvantages were analysed to detect whether the challenges and worries are dissimilar in different parts of the world. Three respondent groups were created: Northern America, UK and other European countries. The analysis shows some indicative differences. Most of the UK respondents stated that there are no disadvantages if the tools are introduced correctly. In other European countries group all respondents had observed or heard of some disadvantages. In this group the concern that workers focus too much on the tools in and stop thinking by themselves was emphasised. The respondents from Northern America reported the extra burden and time required to use all the tools as the main challenge.

Conclusions

The international survey showed that the organisations had implemented the HU programmes as a response to peer pressure and experienced need to improve their safety and business performance. The study indicates that human error reduction is believed to influence safety by reducing unwanted events. The HU programmes were also expected to contribute to multiple other goals such as educating the organisation about the human role in safety. Few respondents indicated clearly what kinds of measured benefits they have perceived due to HU programme.

The most often mentioned disadvantages associated with the HU tools included that they complicate and slow down work tasks, that workers stop thinking by themselves, and that using HU tools misdirect the focus from the tasks itself to the tool. There were some differences between Northern American, UK and other European respondents in the perceived disadvantages, indicating that national culture needs to be taken into account when designing programmes for supporting human performance.

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Abstract	In recent years most Nordic nuclear power plants have implemented so called human performance programmes. Typically human performance programmes apply *human performance tools (HU tools)* to maximize failure free operations by preventing and/or catching human errors. Despite the prominence of human performance programmes, there is little scientific literature on the premises behind the HU programmes. Also, the concrete beneficial effects from using HU tools in nuclear power plants remain elusive. This document describes the results of a Nordic research project HUMAX which aims at providing knowledge of the impacts of the HU programmes and to support implementation of effective HU tools. The focus is especially on maintenance activities. In 2013 and 2014 HUMAX project carried out three case studies in Nordic nuclear power plant maintenance. Furthermore HUMAX disseminated an international survey to human performance experts around the world to gain insights into the motives underlying the human performance programmes and the benefits received. The results show that HU tools are introduced as error prevention techniques and it is believed that reducing the number of human errors improves nuclear safety. However, the study suggests that it may be difficult to prove measurable improvements in nuclear safety indicators. The benefits of HU tools included other than directly nuclear safety related benefits such as decreased number of occupational safety incidents and less rework. There was a general fairly positive attitude towards the use of HU tools amongst the maintenance personnel when the tools were seen as supporting the quality of work rather than as controlling methods. If not carefully planned, HU tools may complicate and slow down work processes and cause frustration among workers. A risk that task execution becomes mechanistic and HU tools dampen workers' self-initiative was reported. In order to facilitate mindful use of the tools it is crucial that the implementation process starts by thorough discussion on why, how and when each of the tools should be used in the unique cultural context. HU tools should not be used for compensating system problems, such as poor working conditions. The results of the study have been summarised in a set of recommendations to support the HU programme implementation process.
Key words	human error, nuclear power, safety culture, safety management, maintenance

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