Enhancing the Performance of Safety Critical Task Analysis: The Goldilocks Problem and Marginal gains

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In the UK, sites governed by the Control of Major Accident Hazard (COMAH) regulations are required to identify COMAH-critical tasks and use Safety Critical Task analysis (SCTA) to identify where they are vulnerable to human failure, and the factors that might make those failures more likely. However, SCTA can vary in its application and output. We reflect on many years of experience of conducting SCTA and apply two concepts for thinking about this variability: 1) the Goldilocks problem highlights how organisations balance efficiency and thoroughness in the conduct of the SCTA; and 2) marginal gains shows how small changes can aggregate to have significant impact on SCTA processes and outputs.

1 Introduction

Safety Critical Task Analysis (SCTA) vary in their quality of application and output. Smith and Koop (2011) list conditions that affect SCTA performance, but there has been relatively little other work to build on this. As a company we have been practising SCTA for over 30 years, evolving and improving our practices along the way. To identify some of the features of what makes a SCTA a success, and where it could be improved, we reflect on these experiences and report our analyses. To help shape our findings and communicate the results we use Team GB cycling team's approach 'aggregation of marginal gains' as a lens to study SCTAs. Essentially, this focuses on how small improvements can lead to significant performance gains. We also highlight the issue of the Goldilocks problem, which seeks to balance gains in efficiency and thoroughness so SCTA is neither too fast and shallow nor too slow and effortful with a potentially redundant level of depth.

2 Safety Critical Task Analysis

Control of Major Accident Hazard (COMAH) regulations apply to sites in the UK that need to identify COMAH-critical tasks, analyse their vulnerability to human failure, and review the factors that might mean these failures are more or less likely (HSE, 2016). The overall aim is to optimise the performance of people who carry out COMAH tasks so they are more reliable and less vulnerable to error. ALARP and Hierarchy of Control (HoC) principles are applied, factors influencing the performance of people are managed (for more detail see, for example, Energy Institute, 2011).

After COMAH-critical tasks have been identified Safety Critical Task Analysis (SCTA) is performed on those tasks to meet COMAH requirements. SCTA generally involve some sort of task analysis, a human failure analysis, and an analysis of the Performance Influencing Factors (PIFs) that influence the likelihood of failure. So this is not just a desktop exercise as frontline operators should be consulted as part of a consensus group to engage with how the task is completed in practice, and there should be a walkthrough/talkthrough of the task so Human Factors issues can be assessed in-situ.

SCTA has a variety of synonyms, e.g. Safety Critical Task Review (SCTR), Human Reliability Assessment, Human HAZOP, and Human Factors Critical Task Reviews (HFCTR). HFCTR is our preferred label because it emphasises that it is a Human Factors based approach and the focus is on human performance issues, that it is focused on the most critical tasks, and that it is a task review which goes beyond a task analysis which is a sub-component of the HFCTR. Most versions of HFCTR have their roots in SHERPA (Systematic Human Error Reduction and Prediction Approach) (Embrey, 1986, 2018). We will refer to the process at HFCTR in the rest of the document.

The Energy Institute (2011) provide thorough guidance on how to conduct HFCTR. This includes markers of low and high quality HFCTR (Table 1 & 2). Human Reliability Associates (HRA) has worked in this area for many years and conducted many SCTA. We also train clients in how to conduct HFCTR and review their HFCTR processes and outputs. This exposure allows us to see variability in how HFCTR is conducted, variability in what is produced, and understand some of the issues that influence this variability (Furniss et al., 2019). By understanding what influences this performance variability we are better able to advise clients and raise the standard of HFCTR. HFCTR is part of our reflective practice (Schön, 1992) whereby we can share knowledge about issues with safety critical tasks like work permits, isolations, checks and reinstating safety systems (Henderson et al., 2017), road tanker off-loading (Furniss et al., 2019b); and propose innovations in how HFCTR is conducted (Henderson et al., 2019).

In this paper we build further on our work that looks at the performance variability of HFCTR (Furniss et al., 2019a). The framing we bring to the issue is one of marginal gains, i.e. how can small adjustments be made in the HFCTR process to deliver better results. However, the application of these ideas also led us to articulate another issue with HFCTR, which is captured in the Goldilocks principle, i.e. clients want something that balances efficiency and thoroughness – not an analysis that is too quick but potentially shallow, and not an analysis that is too slow with a potentially redundant level of depth.

These sorts of reflections are of practical value and not just of theoretical interest. We have observed clients that do HFCTR in name, and tick most of the major features that you'd expect to find in a HFCTR, but their processes left us feeling uneasy about the quality of the work. It can even be challenging pointing to any single significant event that would cause this unease, rather it appeared the accumulation of many smaller things. Potentially an imbalance towards being quick and efficient rather than being careful and thorough might be at play.

Table 1: Markers of low quality HFCTR (adapted from Energy Institute, 2011)

Task selection and review are drawn into procedural details and the link to Major Accident Hazards (MAH) becomes lost. Selection of tasks is limited in scope, e.g. focus is on operational tasks and maintenance and non-routine tasks are missing.
The study looks like a theoretical or desktop exercise with little involvement of frontline personnel.
PIFs are not identified or are not linked to actions and recommendations if they are. Inappropriate use of HoC, i.e. PIFs like training are emphasised before considering whether the hazard could be removed.
Failure to identify issues of non-compliance. Failure to incorporate past incidents at the site and incidents that are known in industry.
Evidence of gaps in skills and knowledge in the consensus group team.
Resulting documentation unusable as a decision-making or communication tool. Over-complex method with little chance of being used in a widespread manner (i.e. only a niche tool).
Failure to recognise reasonable additional steps to improve safety. No clear management or auditing of HFCTR recommendations.

Table 2: Markers of high quality HFCTR (adapted from Energy Institute, 2011)

The selection of COMAH-critical tasks and their reviews have clear reference to Major Accident Hazards (MAH); a range of different task types are selected.
A high level of staff engagement is involved through interviews and observations to support document review.
SCTs are represented visually or in tables to aid communication. Outputs are in clear tabular form.
Failure uses a systematic process, based on the use of guidewords to maxi.
The consensus group who contribute to the HFCTR have an appropriate mix of skills and experiences.
HFCTR processes are matched and integrated with other aspects of the site's safety management system (e.g. cross-referencing with other safety activities).
HFCTR recommendations are regularly audited and reviewed as a site key performance indicator (KPI).

3 Aggregation of Marginal Gains

The Aggregation of Marginal Gains was an approach to performance improvement that was made famous by the British Cycling Team who won 10 gold medals at the 2008 Beijing Olympics. Sir Dave Brailsford was the performance director who is attributed with this pioneering approach for the team. Ten years on we are used to the British Cycling Team and cyclists being a dominant force on the world stage, but before the landmark Beijing Olympics they struggled to find success.

Rather than focusing on big changes to achieve big success Brailsford wanted to think small, look for the small 1% gains they could make in every area of their preparation and adopt a philosophy of continuous improvement (HBR, 2015). Some of examples of marginal gains include testing clothing fabrics in wind tunnels, hiring a surgeon to teach the team how to wash their hands properly to ward off germs, review of pillows and mattresses, diet, racing strategies, bike seat comfort and even using white pant so impurities could be spotted more easily (HBR, 2015). However, success was not immediate, one lesson was that the critical success factors need to be attended to and performance improvement conducted around these rather than getting distracted with peripheral issues (HBR, 2015).

The Aggregation of Marginal Gains was also applied to the more recent sub 2-hour marathon success. Eliud Kipchoge's final time was 1 hour 59 minutes and 40 seconds. There was an army of people that contributed to this achievement, including data scientists. The ideal location was selected considering the weather, humidity and wind; Kipchoge had 41 rotating pacemakers to help protect him from the wind and their formation was carefully choregraphed using computer simulations, and a roundabout was even temporarily moved so it didn't adversely affect the pace of the runners (BBC, 2019).

To summarise, the approach here is to look for the small gains in the many different factors that influence performance, which can accumulate into large gains, rather than looking at a single thing to change in a big way. Also, whereas a 1% gain is not noticeable on its own, if these gains are treated accumulatively over time the gain in 1% performance advantage every day would lead one to being 37 times better over a year, whereas a 1% decrement in performance each day would lead to a decline to nearly zero (Clear, 2018).

4 The Goldilock's Problem: Efficiency-Thoroughness Trade-off

What does better mean? For the British Cycling Team and Kipchoge it was quite simple, as speed was the single metric that needed to be maximised. However, in the pragmatic world of HFCTR things are a little more complicated. We are not aiming for the best quality HFCTR in the world. Indeed, our clients might not thank us if we proposed to take months to do the analysis

rather than days. There is a need to be efficient as well as thorough, but these goals often work against each other, and so we are faced with a trade-off (see Efficiency Thorough Trade-Off (ETTO) principle, Hollnagel 2017).

This issue is alluded to in HFCTR guidance when it states that the detail of a task analysis should be proportionate to the criticality of the task steps and that there is a trade-off between 'thoroughness and practicality' when applying lists of human failure guidewords. However, these trade-off decisions could also stretch to how long is given to each HFCTR, who is involved, how thoroughly they are engaged and prompted to contribute, how thoroughly a walkthrough/talkthrough is conducted, etc.

The Goldilocks principle gets its name from the children's story *Goldilocks and the three bears*. where Goldilocks tries to find the porridge temperature which is 'just right'. This notion of finding the 'just the right amount' is understood and applied in a wide range of disciplines. One well known application is in astrobiology where the Goldilocks zone in solar systems represents that area away from the star which is neither too close and hot nor too far away and cold to support life.

Similarly, there is a Goldilocks zone for HFCTR which is neither too fast and efficient nor too deep and thorough to deliver the pragmatic and proportionate approach to risk assessment that is alluded to in the guidance. Interestingly, the Goldilocks zone is relative to the nature of the task and the risks involved, accepted cross-sector standards, the company's culture, management understanding and investment in Human Factors and the HFCTR processes, and regulatory scrutiny.

We have tried to depict a scale in Table 3 where a Goldilocks zone needs to be found. From a trade-off perspective a marginal gain in one area may lead to a decrease in performance in another area. Organisations may want to focus efforts on making the process faster and cheaper, or they may want improvements in quality despite extra efforts. This trade-off needs balance, but ideally performance gains could be made in both areas without significant costs.

Table 3: Variability in the application of HFCTR processes and how efficiency and thoroughness may be traded off to find a Goldilocks zone that is just about right

Scale of decreasing efficiency and increasing thoroughness	Examples of HFCTR variability
Where speed and expenditure is prioritised…	1. No real task analysis is performed as the team believes using the procedures to do a risk assessment from is an adequate substitute, only a narrow set of failure modes are considered (e.g. omission and incomplete) as well as a limited set of PIFs. A walkthrough/talkthrough may not be done.
	2. Not the whole task analysis, or only in depth in some places, e.g. where critical risk is identified, only a narrow set of failure modes are considered (e.g. omission and incomplete) as well as a narrow set of PIFs. A walkthrough/talkthrough is done just to confirm there are no obvious problems.
	3. Task analysis of the whole task, the main applicable failure modes are considered systematically, and significant PIFs are identified for each failure mode. A walkthrough/talkthrough is done of the whole task and relevant issues specific for that task are probed.
	4. Thorough task analysis of the whole task, every relevant failure mode systematically considered for each step, and a thorough review of PIFs specific to each failure mode that is identified. A walkthrough/talkthrough is done of the whole task and issues are probed for the task and its surrounding environmental factors.
Where quality and thoroughness is prioritised…	5. Thorough task analysis of the whole task, every relevant failure mode systematically considered for each step, and a thorough review of PIFs for each failure mode that is identified. PIFs are weighted differently depending on their influence on the likelihood of failure and their perceived quality is numerically rated by staff. A walkthrough/talkthrough is done of the whole task and issues are probed for the task and its surrounding environmental factors.

5 Identifying Major, Medium and Marginal Gains

While reflecting on the potential for marginal gains associated with HFCTR it seemed that these were at different levels or different orders of magnitude compared to others. We have tried to capture this spectrum of different gains and losses in the following reflections.

5.1 Planning and Preliminary Analysis (upstream)

This is an important step in the HFCTR process as it lays the foundation for a successful project. Expectations and requirements need to be managed so appropriate resources are made available for the workshop. For example, if access to knowledgeable safety specialists and personnel with direct experience of the task being analysed is not provided then they may not be fully engaged .

It is essential to have a room with a shared display (ideally a projector, but a whiteboard or Post-it notes can be used) so an interactive task analysis can be conducted, which provides the focus for the work of the consensus group.

To make the most of people's time we request procedures ahead of the workshop which allows us to do a preliminary analysis. This has obvious efficiency gains because we perform a first pass through the task analysis while away from the group. This also prepares us, as the facilitators, better mentally for engaging with tasks we can be unfamiliar with or that have nuances in practice. Preparing issues and questions ahead of the consensus group can bring both gains in efficiency and thoroughness.

Experiences from clients where this has not gone well include one who approached us as they wanted to adopt more workable systems and processes to conduct HFCTRs. One of their main issues was that they found it challenging to secure time from staff to take part in the consensus group workshops. They followed a manual process and said they requested three to four days with staff. We expected to half this time by introducing the preliminary analysis before staff are required, and by using specialist HFCTR software to speed up the Hierarchical Task Analysis (HTA), failure and PIF analysis.

5.2 Workshop analysis and walkthrough

This is the main stage of the HFCTR process where the task is analysed, and a failure a PIF analysis is conducted.

5.2.a Participant engagement in consensus groups

The consensus group workshop needs to be well organised and requires good engagement from participants. The HFCTR should have a multidisciplinary team that also works together well including someone with Human Factors knowledge, a process or safety engineer and at least one field operator. The HFCTR facilitator will have a large impact on performance, both from a technical point of view but also in terms of managing the group process.

Rapport needs to be built so the team work effectively together. We find that introductions and a presentation at the beginning of the workshop can work well to explain the aims of the workshop, the regulatory context, the process, specific major accident hazards to do with task and the Human Factors no-blame approach. A safe space should be created for field operators to share the 'warts and all' realities of their work, so non-compliance issues can be identified, discussed, understood and addressed. Probing for non-compliance might include highlighting places where such issues might be suspected, e.g. if people are expected to monitor a road tanker offload in the cold and rain, only tightening three bolts on a fitting rather than four, or checking safety equipment that should have already have been checked.

HFCTRs can be tiring and so we try to break up the workshop with breaks and walkarounds to keep people motivated and attentive. On occasion, videos about major accidents have been shown to break up the workshop, as these can focus minds on how relatively simple errors and issues of non-compliance can conspire to cause major accidents.

A simplified view of the task analysis stage is that it is just there to break the task down into a series of steps. Variability at this stage includes clients who didn't see the point of doing extra analyses and just use their procedures rather than doing a separate task analysis. We prefer to emphasise the 'analysis' aspects of task analysis, as it is the first stage of really trying to interrogate the task to understand work-as-done rather than work-as-imagined, i.e. how do field operators actually perform this task in practice. This review is aided by having a reflective environment where people feel empowered to contribute, time to discuss the task steps appropriately, and an interactive graphical display so participants can collaborative and change things in real time. We find a graphical display allows people to point to task steps, review and move them more easily than a table of text, which is less penetrable in comparison.

The failure analysis can be a laborious process, especially if one has to do it by hand or transfer a task analysis into tabular form to then search through the applicable failure modes for different task steps. Specialist software tools are available that can automate and alleviate some of the work. This has gains for efficiency and thoroughness. Generic software tools such as Excel can also be adapted and applied.

The PIF (Performance Influencing Factors) analysis can be done at the level of task steps and more generically for the task overall. Gains in thoroughness can be achieved with the specialist HFCTR software tools which have a catalogue of PIFs associated with each failure mode, which can be weighted and scored. However, we often find these gains in thoroughness can come at the cost of efficiency, so often for normal SCTs noting significant PIFs that reduce and increase the likelihood of error can be enough. These extra gains of thoroughness may be desirable for steps that are particularly critical or vulnerable to failure, or where there is heightened scrutiny due to a recent incident.

5.2.b Directing effort where it is most needed

The HFCTR should be focused on the Major Accident Hazards (MAHs) and not get to bogged down or distracted by procedural details (Energy Institute, 2011). As mentioned above, we find that presenting the MAHs associated with the task in the opening presentation can really focus the workshop on what matters. However, this isn't just a case of presenting the MAHs but getting agreement about what these are and discussing existing protections. This also allows opportunity to clarify what is of less interest for the HFCTR process, e.g. so field operators understand why personal safety is more of a peripheral interest for this activity.

If members of the team have done HFCTRs for similar tasks either within and across organisations then this will allow them to quickly focus in not only on candidate MAHs but also Human Factors issues related to the task. This could be found in an experienced HFCTR facilitator.

Decisions about how much to drill down into details of sub-steps in a task analysis are subjective, where non-safety critical steps can be represented briefly and safety critical steps drilled down into further detail (Energy Institute, 2011). This is for efficiency gains and to prevent the team from becoming overwhelmed with procedural details. The right tools can bring efficiency and thoroughness gains in how this is managed. For example, a risk matrix can be used to determine where the risks are in a complex HTA, so the team knows where to focus their attention in terms of further task breakdown and risk assessment activities. Furthermore, interactive HTA software can make dealing with a complex task analysis much simpler. Performing the whole task analysis thoroughly has gains for procedure integration and competency management (described later).

5.2.c Enhancing the Walkthrough/Talkthrough

The interactive observation is an important element of the HFCTR. This is where the consensus group are stepped through the task by a field operator so it can inform the developing task analysis, and so PIFs can be assessed in the environment e.g. is a gauge hard to read because it is too high/low or challenging to interpret because it is in different units, is the task performed in low light and is lighting adequate, is the environment cluttered or noisy, and are buttons and levers clearly differentiated and labelled? It is advisable to take photos on the walkthrough which can be used to support issues and recommendations in the report, for clarity and for evidence that this activity has been carried out.

A multidisciplinary team is also useful for the walkthrough as people will have different mindsets and perspectives, which can lead them to notice different things and learn further from each other about the task. A Human Factors professional will be attuned to applied psychological theory about different types of human error, safety science and accidents, and experience of prior HFCTR and non-compliance issues. The safety engineer will be attuned to hazards and why the plant is designed the way it is from a technical point of view. The field operator should have a day to day understanding of the plant and how the task is actually conducted, including issues of non-compliance and workarounds. Consensus still needs to be managed in this team in what is and is not considered a problem. For example, the fact that two adjacent pumps look similar may or may not be a problem depending what they might be pumping where, and the field operator can give their opinion about what the task is like to do at night time if the walkthrough is conducted during the day.

We generally find that at least a notebook is needed for the walkthrough as a lot of information can be covered quickly which might otherwise be forgotten. If the task analysis is already underway then a draft set of the new procedures or HTA can be printed to provide some structure for the observations and the notes. Questions and issues that have already arisen from the task analysis could provide areas for prompts and further investigation on the walkthrough, thereby enhancing the information that is gathered during this activity.

5.3 Following Up Actions (downstream)

The HFCTR is meant to feed into risk management activities, inform procedure design and competency management of MAH critical tasks, and feed into organisational learning.

5.3.a HFCTR reporting

The task analysis, failure and PIF analysis can generate lots of information and lengthy tables that can be hard to access and digest, especially for people within the organisation who haven't been part of the process. This means that some form of executive summary should be designed to summarise the MAHs, issues and recommendations. This executive summary has been developed and refined over many years at HRA, which includes reference to the Hierarchy of Control and PIF management recommendations. It also has space to invite a response from the site so it is already encouraging follow on thought and action from the work, rather than just being a document to be filed away.

5.3.b Links to procedures and competences

The HSE (2005) require a clear link between the HFCTR and procedures and competency management so MAH are controlled. For example, procedures should contain appropriate warnings and critical information about the control of MAH steps; and training should include the task-based knowledge and skills needed for MAH steps. This could seem like a lot of extra effort, and even separate follow on projects. However efficiency gains can be achieved by using the HFCTR information already developed, e.g. some HFCTR software has templates where procedures and competency standards can be exported from the HTA, failure and risk assessment that has already been performed, so it is making the most of that work that has already been done.

5.3.c Organisational learning

The documentary evidence and audit trail of the reports above are typically what people see as the formal outputs of the HFCTR process. However, perhaps more subtly, there is the enhancement of organisational learning. The HFCTR consensus group when managed well allows people from different disciplines and departments to come together, share information and learn from each other. For example, this might be the first time management learn about the pressures that frontline staff work under and why issues of non-compliance arise, about valves that pass and the workarounds operators perform, and about high-level alarm breaches that are not reported. This helps to bridge work-as-imagined and work-as-done, but it will only work effectively if the right people come together in the right way.

6 Discussion

HFCTR has well documented guidance, which includes markers of low and high quality work (Energy Institute, 2011). However, the organisation and application of HFCTR in practice still requires thought. This is best considered as part of ongoing reflective practice as new projects bring new challenges, and further work leads to new learning. The framing of marginal gains has helped us reflect on our practices and articulate features of that which help create successful HFCTR.

Marginal gains have been recognised in the preparation, conduct and delivery of the HFCTR process. Some gains seem quite independent, simple and straightforward, e.g. bring a note pad and pen or task analysis print out to help shape and record questions during the walkthrough. Others are quite clearly linked, e.g. requesting front line staff are available, creating an atmosphere where they are willing to share issues, where the task analysis can be thoroughly discussed and adjusted if necessary, will all feed into more significant gains for organisational learning. This idea of how gains relate together may go beyond principles of summative aggregation, alternative framings might explore how gains interact and positively resonate together to produce larger effects (Furniss et al., 2016).

Of course, not all factors will be optimised. In practice adaptation may be needed to compensate for deficiencies, e.g. if frontline staff are only available for an afternoon. In some cases, a number of areas may be deficient leading to a relatively shallow analysis, e.g. a proper task analysis may not be performed, the failure analysis may be rushed due to efficiency pressures and domineering facilitation may not lead to an environment conducive for exploring issues. However, an organisation may see this configuration a success if they are prioritising efficiency over thoroughness.

Finding what configuration of HFCTR works in practice, and satisfies the competing demands captured in the Goldilocks zone is an ongoing issue and part of reflective practice. More global gains in both efficiency and thoroughness can come from more significant changes in the configuration of HFCTR processes. At HRA we do many HFCTRs and so the savings in time and effort, and added thoroughness in HTA, failure and PIF analysis make investing in specialist software worthwhile. Developing presentation and reporting templates can also lead to ongoing performance gains. There is a deeper point here about adopting and organising a system of HFCTR practice that works for the organisation, this is not just about training individuals but providing the right resources to set them up for success.

A limitation of this work is that we are reporting from just one consultancy, HRA, albeit with many years of experience in this area we are limited in the way we have developed and configured what we believe to be successful HFCTR processes. Future work could invite a wider range of perspectives, however organisations might be hesitant to share tips and tricks for performance gains when they see this as an advantage over their competitors.

Future work could also use information about marginal gains as the basis for developing an assessment tool for HFCTR. It would be useful for organisations to benchmark their processes against best practices and to see specific areas where gains in thoroughness and efficiency could be made. Indeed, with a greater emphasis being placed on organisations to develop internal competence to conduct HFCTR this sort of assessment tool could help with the coaching and development of this competence.

7 Conclusion

HFCTR is not just a technical activity, it is a sociotechnical process involving people, process, tools and artefacts that can be studied and enhanced. This work starts to make observations and recognise marginal gains in what makes HFCTR succeed rather than fail. Marginal gains can be sought in different areas of the HFCTR process, including its preparation, conduct and delivery. Some gains can be quite simple and independent while others may have a more general impact on the efficiency and thoroughness of the activity. How organisations choose to configure their own HFCTR processes is an ongoing issue and should be part of their reflective practice, to check that requirements are being met. A balancing between efficiency and thoroughness for HFCTR will have to be made, whereby the Goldilocks zone of HFCTR is found, which is not too efficient and not too thorough, but just about right for that task and those circumstances.

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