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HCI - H is also for Hazard: Using HAZOP to Identify Undesirable Consequences in Socio-Technical Systems

HCI - H is also for Hazard: Using HAZOP

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Technical interventions in socio-technical systems are often portrayed overly positively but can also have undesirable consequences which can directly impact adoption and sustainability. Systematically identifying what might go wrong is not straightforward. This paper presents the iterative development, including an early validation trial, of an HCI-focused collaborative brainstorming approach to identify deviations from design intent that harm people. The established Hazard and Operability Study (HAZOP) guide word based method, not applied before in a HCI context beyond safety-critical systems despite extensive use in other disciplines, has been adapted and applied. Motivated by the need to enumerate impacts of technology on marginalised individuals and their communities, and utilising the lead author's previous experience, a more human-orientated 'HCI HAZOP' was investigated. Using two feasibility studies and two pilot studies, the adapted method has been trialled, evaluated and refined. The studies' findings demonstrate the usefulness of the method identifying undesirable consequences, even by novel practitioners without any prior training. The paper presents the adaption as a methodological contribution, an application of 'HCI HAZOP' through studies using scenario-based design artifacts identifying limitations and benefits, and guidance materials for use by other researchers.

CCS CONCEPTS • **Human-centered computing ~ Human computer interaction (HCI) ~ HCI design and evaluation methods** • Human-centered computing ~ Collaborative and social computing ~ Collaborative and social computing systems and tools • Human-centered computing ~ Interaction design ~ Interaction design process and methods ~ Scenario-based design

Additional Keywords and Phrases: HAZOP, socio-technical, harms, risks

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1 INTRODUCTION

Wiener's influential cybernetics book [52] on information flow and feedback self-regulation, draws attention to automation systems' "*great possibilities for good and for evil*" and he later warns technology's goals may not be the same as humans' [53]. Carroll [7] added that every change to a system has consequences, some of which may be unexpected, and some of which are undesirable. The possible negative ethical, political and social impacts of technology research, design and deployment have been receiving increasingly deserved attention with demands for more transparency [44]. Wong et al [54] describe how "*relations and practice*" around artifacts contribute to variability in the benefits and harms which themselves are co-constructed in socio-technical systems. Such harms may be distractions [37], burdens of varying degrees [38], affect health and assets [21], and can extend to malicious abuse [16,23,46]. Despite agreement on the importance of identifying harm, doing this in practice is very challenging and the topic of developing systematic methods to address this during early-stage design has not received sufficient attention in HCI.

This paper presents an adaption of the Hazard and Operability Study (HAZOP) assessment technique [21,25] to a HCI context. HAZOP identifies effects (injuries to people, loss of life or serious damage to property [28]) through a guide word based analysis and is the most evidenced and mature of many hazard identification techniques [15]. It is a qualitative bottom-up inductive methodology, which systematically and comprehensively examines design artifacts to identify hazards element-by-element, considering 'deviations' from design or operating intentions (the desired or specified range of behaviours which fulfil requirements [21]), possible causes and their consequences.

As a former chartered chemical engineer, the lead author is experienced in HAZOP studies. When the need arose to identify digital intervention impacts on citizens in a different project, HAZOP was considered. It was then recognized that its use for human-centric HCI research has not been investigated by others. However, HAZOP's inductive methodology appeared to be a good fit for complex socio-technical systems where deviations arise from individual and community use of technologies and from the wider ecosystem such as externalities over which people have little control (e.g., low-resource communities [9]). These can all have negative consequences – on individuals themselves, on other people, on communities, on society and on the technology. This led the authors to examine whether a methodical process based on HAZOP is practical and has merit for helping identify negative consequences within HCI research on socio-technical systems early on in the design process, to identify deviations that lead to detrimental events from an individual's perspective rather than the more typical deviations that may lead to what organisations consider 'unsafe' situations. As such, the objective was to investigate whether HAZOP can assist enumeration and exploration of Carroll and Rosson's "*negative claims*" [8], which are adverse consequences of a system feature, based solely on design artifacts, i.e. without operation or observation of the intervention, process or system. The contributions of this paper are threefold: 1) a methodological type contribution by presenting an adaption of the HAZOP guide word approach for a HCI context; 2) an application of this 'HCI HAZOP' methodology through two feasibility studies and two pilot studies using scenario-based design [42] artifacts, to develop, evaluate, and update the method, identifying limitations and benefits; and 3) guidance materials (further details of which have been published in the associated repository).

2 BACKGROUND AND RELATED WORK

Consideration of harms in HCI-related research can often be framed in terms of ethical principles that guide research conduct. Any consideration of harm, ethical or otherwise, depends on the impact perspective as well as values [18]. Ethical guidance and related institutional review processes which require risk assessments and consideration by more experienced researchers can identify and avoid some hazards before research commences [49]; these may have standard checklists [17], requirements for research for 'vulnerable participants' but will not predict all harms [17], especially in socio-technical systems [49], where potential or actual harms may "*emerge*" later, and many harms will not necessarily be ethical concerns. Baumer and Silberman [4] proposed three questions to consider whether a technology intervention in inappropriate or harmful, but these are broad-based, and one "*Does a technological intervention result in more trouble or harm than the situation it's meant to address?*" reveals there is still a need to determine "*trouble or harm*". Case studies, checklists and prompts such as ideation cards can all help identify harms, but they start from finite lists. Actual negative impacts on people may be discovered through trial studies [33] but these involve participants 'discovering' the hazards (i.e., top-down post-event hazard analysis, rather than bottom-up prior hazard identification). If these are field-based rather than lab-based, contextual and situational factors mean there is less control and thus greater risk (e.g., [32]). Identification of hazards in advance is preferable and a number of HCI methods including GOMS (Goals, Operators, Methods and Selection rules) [6] and HTA (Hierarchical Task Analysis) [24] can be used to break complex systems down into simpler parts for further analysis. These can be used in error and hazard identification processes [1] but are usually [15] complemented by separate hazard identification or hazard analysis techniques. GOMS and HTA use formal analysis and modelling of human behaviour and experience in "*well-specified tasks*" [42]. Such specification within a socio-technical system is made more difficult by the inclusion of individuals and communities, with varying motives, and in which the system itself is not static. Where full definition of tasks is impossible the lightweight Scenario-Based Design method can be of use.

2.1 Scenario-Based Design

In the established Scenario-Based Design (SBD) method, scenarios are stories used to describe people's actions using systems to undertake tasks, comprising a series of events, actions and goals, emphasising people and their experiences [7,42]. Utilised in people-orientated design, they offer opportunities for designers to reflect on their ideas [7] and to communicate how an interactive system might be used. Rosson and Carroll [42] explain scenarios can be used to understand and consider desirable and undesirable consequences of designs (to address the 'problem') and that problem scenarios are central to the outputs of SBD. The set of SBD scenarios need to provide broad coverage of usage activities [8], serving as "*requirement criteria*", but Nathan et al [34] found that, in practice, many such scenarios only illustrate technology being used by direct stakeholders in the intended manner with positive impacts. Identifying "*what could go wrong?*" [8] is as important as identifying how user goals are met. Revealing undesirable consequences requires consideration from the perspectives of different actors and artifacts; a negative consequence to an organisation may be tolerable but the same event may be highly significant to an individual. Carroll and Rosson provide suggestions for how to enumerate these negative claims from a typology of user concerns [8,42]. Rosson and Carroll [42] describe how a systematic evaluation can be undertaken by basing the scenario generation process on user concerns and user cognitive behaviour, but there remains a need to identify other types and causes of deviations. Nathan et al [34,35] introduced "*value scenarios*" to extend SBD to consider indirect effects on other people and wider society relying on a choice of values the design "*should support*" (e.g., fairness human dignity, inclusivity) and gathering views and values from users and stakeholders rather than using design materials directly. Vincent and Blandford [47] extended SBD to examine "*real-use*" variations – deviations such as user-distraction, the use of shortcuts, choices of prioritising speed vs safety, behaviour variability and interactions with other artifacts. However, these are not broad *systematic* methods. The closest to such an approach is tagging in Kurosu et al's Micro-Scenario Method [29], which is a top-down breakdown of a problem description into its smallest constituents based on analysis of fieldwork data (i.e., requiring an existing implementation), rather than the systematic bottom-up enumeration from design information in HAZOP's guide word driven approach.

2.2 Hazard and Operability (HAZOP) Assessments

HAZard and OPerability (HAZOP) assessment development began in the 1960s [30] within Imperial Chemical Industries' industrial manufacturing plants, leading to a mature and sophisticated technique by the 1980s [25,45], being relatively simple and intuitive compared with other risk management techniques [15], and subsequently adopted as an international standard IEC 61882 [21]. HAZOP helps identify what can go wrong *during operation* and what the consequences will be qualitatively [25]. Hazards are potential sources of harm (damage/injury) [21] to any part of the system including people and outputs. The consequences considered in industrial processes were harms caused to human operators, plant, equipment and product [25]. IEC 61882 describes how HAZOP studies are "*particularly useful for identifying weaknesses in systems (existing or proposed) involving the flow of materials, people or information, or a number of events or activities in a planned sequence or the procedures controlling such sequences*" and have been used beyond industrial processing such as people transportation, software development, organisational change, procedural and contractual documentation. In 1997 Rasmussen and Whetton [40] proposed representing a process plant as a socio-technical system with an associated identification of high-level hazards by examining intents, constraints and methods for each element.

2.2.1 HAZOP method

The HAZOP assessment procedure [21] comprises four steps: definition, preparation, examination/documentation and follow-up. Organisation-dependent formal initiation is followed by definition of scope (boundaries and interfaces, applicable legislation, intents/requirements and norms) and assessment objectives. The *study team* is defined and membership, roles and responsibilities assigned. Roles are a *study leader* trained in using HAZOP to facilitate the assessment and "*not closely associated with the design team and the project*" [21], *study team* participants (typically designers, operational users, specialists and system maintainers [45,51]) and a *recorder* to document proceedings. The preparation step includes development of a formal study plan, collection of data and documentation, and selection of the 'guide words' (see Table 2). These are used in a "*deliberate search for deviations from the design intent*" by the multi-disciplinary *study team* using their own knowledge and experience. To undertake the examination:

1. Part of the target system being assessed is selected;
2. Its design intent is defined;
3. The part's essential features are identified in terms of discrete 'properties' e.g., equipment or features, or "*the activity being carried out*" or "*data, software, etc*" [21];
4. Each guide word is systematically considered for each property to identify deviations from design intent (and possible causes and consequences), until everything has been examined.

As an example, the guide word 'NO' means to identify any deviation which would lead to the selected part's design intent not being accomplished at all, and nothing else is either. Combinations of each property and guide word may not all be "*credible deviation*s" [21]. To illustrate the approach, consider the activity of making cups of tea described by Dix et al [10] in an explanatory Hierarchical Task Analysis [1] which itself is a method based on the systematic decomposition of an operation specified by a goal and sub-goals. There is a matching HAZOP example in the foundational book by Kletz [25] for making a cup of tea (the intent) using a kettle and tea bag (the design) – see Table 1 where deviations related to the guide words 'NO', 'LESS' and 'LATE' lead to negative consequences on product (tea) quality and lack of product (no tea).

Table 1: Deviations from 'Making a Cup of Tea' HAZOP (Kletz [25])

Guide word	Deviation	Possible causes	Consequences
NO	No water in kettle	No water supply	No tea
		Tap fails closed	
	No understanding	Operator misunderstands instructions	No tea or poor tea
LESS	Temperature	Water below boiling point	Tea too weak
LATE	Tea bag left in cup too long	Distraction	Tea too strong

2.2.2 Digital technology

There is a lack of coverage of HAZOP in HCI literature; a search for 'HAZOP' across the entire ACM Guide to Computing Literature matches 60 paper abstracts or titles, published in software/system engineering, artificial intelligence, safety critical systems and risk journals and proceedings, rather than HCI venues. For example, HAZOP-based methodologies are used in software engineering to assess safety-critical software (e.g., process control systems [27], air traffic control systems [14,36], robot safety analysis [31]). There are more recent examples where HAZOP is being used with a broader viewpoint such as to help understand differences in knowledge and assumptions between engineers (designers) and clinicians (users) during the development of digital healthcare systems where real-world environments differ greatly from use of prototypes [50]. Zendel at al [56] used HAZOP to enumerate checklists to assess hazard coverage completeness of robot computer-vision test data sets and identify gaps in standard test data sets for boundary cases ("*on the brink between specified and unspecified behavior*") and negative cases ("*expected to fail*") [55].

2.2.3 Human factors

Human factors have always been at the heart of HAZOP where it was recognised these (often referred to as human errors or human failures) contribute to, or are attributed to, a significant proportion of preventable past loss incidents [5,19,20,25,41]. Alternative guide words have been proposed to enhance the assessment of human factors [5,12,43], but Ellis and Holt [13] and Aspinall [2] demonstrated that the standard guide words are sufficient. Aspinall [2] explains "*as with any HAZOP a clear design intention (or activity intention) is required*" and the exploration of human-centric deviations should be based on human factor knowledge (execution errors including slips/lapses and informational rule/knowledge mistakes, as well as deliberate violations) and performance influencing factors (e.g., task, personal, organisational), and provides a list of error types and psychological factors. These mirror earlier work by Reason [41] who also lists contributing factors (e.g., unfamiliarity with task, time shortage, poor signal:noise ratio) and to violation conditions (e.g., poor morale, misperception of hazards, inadequate tools and equipment). However, a human factors approach that looks at humans as a source of errors leading to impacts on assets is not appropriate for wider socio-technical systems for a more people-centric focus. Potential difficulties using HAZOP [11,12,25,45,51] that are relevant to a HCI context are inadequate definition of assessment scope, examination of concepts/incomplete designs where the intent is not fully defined, and *study team* experience that is unrepresentative of the socio-technical system.

3 DEVELOPMENT OF HAZOP FOR SOCIO-TECHNICAL SYSTEMS

3.1 Motivation and research context

Previous work by the authors [48] on access to social security benefits had evolved into a study of a UK benefit called Universal Credit which is predominantly accessed online. Issues identified by citizens during a series of interviews had led to the development of proposed interventions as graphical concept scenarios. However, these only presented positive views of each intervention, and the authors wanted to additionally illustrate what might go wrong – especially aspects that could have detrimental impacts on the citizens themselves. The lead author's chemical engineering background encouraged the team to consider the use of HAZOP to identify what could go wrong more systematically. The authors noted some parallels with cognitive walkthroughs [39], but cognitive walkthroughs focus on usability problems and their causes, whereas HAZOP identifies harms.

3.2 From factors to actors

Just as HAZOP was maturing Bannon [3] contributed to a HCI viewpoint shift from treating the human users as problem-generators introducing 'error', to being actively contributing 'actors' whose views should be foregrounded. This HCI move from human factors to human actors whose "*view of the technology we are developing may be very different to that of the designer's*" does not seem to be reflected in HAZOP approaches. Chemical engineer and HAZOP evangelist Kletz [26] did highlight that 'human error' does not mean people have to be changed – their environment (the design, methods of working, training and instructions, supervision, inspection, etc) should be changed. He suggests "*blaming human error diverts attention away from what can be done by better engineering*" and that it should be recognised that "*errors by designers turn operators' slips into accidents*". But to apply HAZOP in a HCI context there is a need to move from thinking of humans as error-making/failing components which impact negatively on business assets to people as both central actors and central to the consideration of the harmful impacts. People's actions are not necessarily errors or other failings, and can relate to normal variability due to circumstances, the situational context, environment, external factors, etc. And as noted, some harms can be co-constructed in operation, rather than being inherent system properties. In socio-technical systems without a focus on safety critical systems, deviations may not necessarily be things which can be or should be eliminated – they need to be understood, acknowledged and considered based on impacts to the primary actors (harms to individuals/communities rather than assets). As an example, in a traditional HAZOP, a company might be concerned with a deviation 'operator error' using a computer control system caused by tiredness with consequences on equipment and product quality or the operator hurts themselves – these are all driven by economic risks - financial loss, legal compliance. Although such an industrial process is not a good example of a human-centric socio-technical system, a HCI context change of viewpoint would emphasize the operator as a person, what contributes to their tiredness, stress and distraction, and even the effects on them if they are sanctioned, demoted, lose their job etc because of their failure to use the technology properly. To differentiate this view from a human factor (error) HAZOP focus, we use the term HCI HAZOP henceforth.

3.3 Scoping as an activity

Hazard identification techniques are applied to a specified scope defining boundaries and system extent, using various design representations with different levels of detail. In SBD, each whole scenario about people using a technology intervention can be considered an activity mediated by tools. Consequently, we have used Activity Theory (AT) [22] as a lens to look at these things and to help define the scope by considering the unit of analysis for HCI HAZOP as an activity. Under AT we will consider within scope all the actors (the person doing the activity and actions - the subject), the community and everyone else involved, their roles (division of labour), the rules and norms within that activity structure, and look at the outcomes (people's meaningful goals). HAZOP examines a hierarchy of parts and their properties (Section 2.2.1); AT is also a hierarchy of objects in which an activity is linked to a motive, an action to a goal, and an operation to a condition. These motives, goals and conditions are the equivalent of the design intents in HAZOP, and may be different to designer's intents, as activities emerge from human needs, rather than the system design.

3.4 Guide word choice

The development of HCI HAZOP started with using the traditional HAZOP assessment procedure, modified to use the harm perspective of the individuals and communities. Given previous findings from human factor HAZOP that the standard guide words [2,13] can be used successfully, the authors chose to commence investigation with these (Table 2). Note the differentiation between qualitative and *quantitative* increases/decreases in design intent, as this arises in later findings.

Table 2: Categorisation of standard [21] HAZOP guide words

Category	Sub-category (note)	Guide word	Meaning
Intent	None (no part of original intention achieved, nor anything else)	NO or NOT	Not done, not completed, no part of the design intention
	Substitution (no part of intention achieved, but something else is	OTHER THAN	Complete substitution
		REVERSE	Logical opposite of intent
	Increase (all design intention achieved but with additions)	AS WELL AS	Qualitative increase
		MORE	*Quantitative* increase
	Decrease (only some of the design intention achieved)	PART OF	Qualitative decrease
		LESS	*Quantitative* decrease
Chronological	Ahead	EARLY	Sooner/earlier relative to time
		BEFORE	Wrong order/sequence before
	Behind	LATE	Behind/later relative to time
		AFTER	Wrong order/sequence after

3.5 Studies based on the methodology

The recommended [25] starting point to introduce HAZOP is to apply it in one or two projects and determine whether it usefully assists hazard identification. In the same way, the development of HCI HAZOP began by application in two initial feasibility studies to explore the viability and usefulness in HCI design for socio-technical systems, and to reveal necessary adjustments or constraints. Subsequently, draft HCI HAZOP guidance materials were created, reviewed, and two pilot studies undertaken. The first was a Trial Pilot facilitated by the lead author and led to guidance material refinements. The second was a Validation Pilot which did not involve the papers' authors in the assessment and was carried out with a *study team* that had considerable HCI experience but no prior knowledge or experience of any form of HAZOP. Its aim was to assess whether other HCI researchers could use the method independently, and to seek their opinions on its usefulness for their own research topics. A comparative summary of the four studies' design properties are shown in Tables 3 and 4; standard guide words were used for all. Scenario A refers to a scenario published by Rosson and Carroll [42], and Scenarios B and C to those created by the authors in other research, which had previously been validated by two other reviewers to check the content was realistic and understandable. Due to pandemic restrictions, the pilot studies were undertaken synchronously using video meetings.

Table 3: Traditional HAZOP features implemented (●) or not (–) in the four HCI HAZOP assessments presented

	Study			
Traditional HAZOP Feature	Feasibility 1	Feasibility 2	Trial Pilot	Validation Pilot
Study leader HAZOP trained	●	●	●	–
Study team knowledgeable about topic	●	●	–	●

Table 4: Other HCI HAZOP assessment properties

		Study			
Attribute		Feasibility 1	Feasibility 2	Trial Pilot	Validation Pilot
Scope of assessment		Scenario A	Scenario B	Scenario B	Scenario C
Assessment duration (minutes)		120	120	75	50
n (total)		1	1	6	6
n (excluding paper authors)		0	0	5	5
Paper authors' roles	*Study leader*	●	●	●	–
	Study team	●	●	–	–
	Recorder	●	●	●	●

An extract from Scenario B, given the working name 'Pre:Peer', is shown in Figure 1. This concept is a digital platform that involves citizens undertaking a series of guided tasks to prepare to make a claim for social security benefit Universal Credit – all undertaken collaboratively with local community support.

3.6 Data collection and analysis

Our approach was related to two aims: to capture information about using the method for iterative improvement, and to capture actual deviation outputs per scenario for the other project. An existing ethical approval from the authors' institution covered the work. We collected data in verbatim transcriptions of audio recordings made of each workshop, the HCI HAZOP outputs (deviations, causes and consequences), our own written post-workshop reflections and, for the two pilot studies, participants' responses to a MS Forms-hosted post-workshop survey to gather feedback about the method. The workshop transcripts were used to identify participants comments about deviations identified in the outputs. HCI HAZOP outputs for the pilot studies were subsequently categorised by main causal actor/artifact (primary actors themselves, other actors, intervention technology, other technologies, other parties, other). Counts of deviations and duration of examination sessions in each study were also noted. Comparisons of the deviation counts, causal element and examination durations were made between the final three studies.

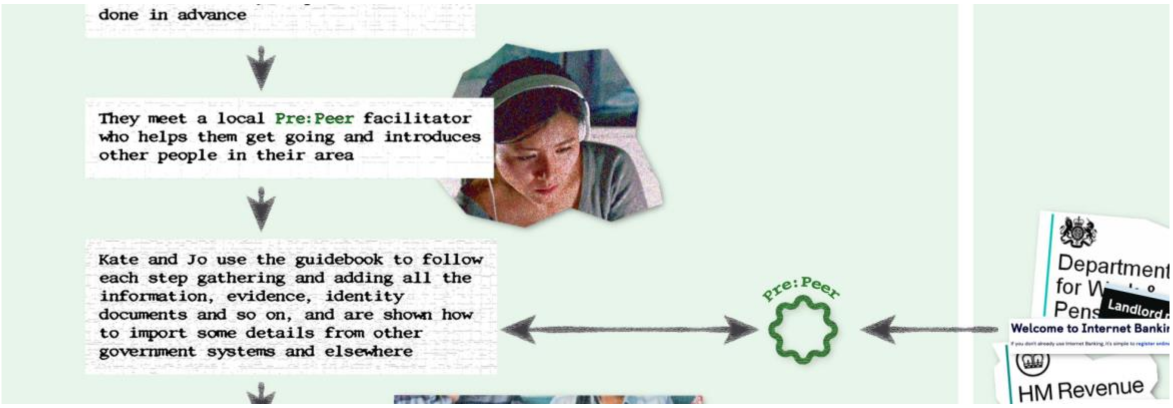

Figure 1: Partial extract from Scenario B
(Component images open source and public domain – attributed fully in supplementary materials)

4 FEASIBILITY STUDIES

4.1 The studies

The lead researcher applied the baseline methodology to two test cases. Firstly to an existing well-documented scenario [42], and secondly to contribute to exploration of the downsides in the authors' other project.

4.1.1 Feasibility Study 1: Application to Scenario A (SBD example)

Rosson and Carroll's worked example of the SBD Framework [42] considers the experiences of a student called Sharon and other members of a university science fiction (SF) club. In the framework's activity design step one of the scenarios (Table 8B [42]), Scenario A, was analysed to assess the plausibility of the approach. The various elements were noted first: actors, artifacts, mediating tools, community and goals. The harm perspective was chosen to be Sharon and the other named SF Club members. The standard guide words (Table 2) were systematically applied in turn to the activities 'Go to the Computer Lab and access a computer', 'Log into the SF Club Online' and 'Join and participate in the discussion forms and post a new topic' i.e., 'activity first' (then guide word).

4.1.2 Feasibility Study 2: Application to Scenario B (Pre:Peer)

Scenario B from the other project was selected for the next target of assessment with the harm perspective as citizens who claim Universal Credit. Like Feasibility Study 1, the lead author undertook all roles (see Tables 3 and 4). Unlike Feasibility Study 1 all the activity elements, including peripheral actors, were first listed to compare a contrasting approach – all the elements were used instead i.e., 'guide word first' (then activity element), without specifically iterating on activity or actions.

4.2 Findings

Limiting the focus to one harm perspective reduced distraction by deviations affecting other actors and artifacts; in alternative assessments with different objectives, these perspectives may need to be examined. It was also noted that deviation identification was assisted by thinking about potential actions by unmentioned actors that might have influence on or affect the impact of harms such as the university's IT department, and citizens in the locality. Feasibility Study 1 identified over 40 negative deviations including e.g., "*Discussion system used to track/stalk participants*" (AS WELL AS) caused by "*Other SF Club online member is too focused on Sharon's life*" leading to consequences "*Loss of privacy by observation; Information gathered used against Sharon by harassment, intimidation or humiliation*". Guide words are separate for qualitative and quantitative intent changes, with quantitative words conventionally first. This makes sense for systems with many more quantitative properties, but less so in these types of people-centric activities. Consequently, the authors reordered the conventional guide word sequence to promote qualitative before quantitative (as ordered in Table 2). The more granular 'guide word first' (then activity element) approach used in Feasibility Study 2 identified 37 deviations for Scenario B during a two-hour assessment. The approach was time-consuming, with many non-credible pairings, suggesting the 'activity first' approach used in Feasibility Study 1 would be better suited for further trials. The authors considered what materials might be required for other researchers to undertake their own HCI HAZOP leading to two subsequent pilot studies.

5 PILOT STUDIES

5.1 The studies

New materials were created: a workshop overview for circulation to the *study team* in advance and an instruction sheet for the start of the workshop; and a two-page step-by-step script for the *study leader* covering workshop initiation, introduction, explanation, the HCI HAZOP process itself and closure activities. Four key documents were created: identifying the scenario activities, each guide word and description (Figure 2); tips to encourage thinking, and a record sheet.

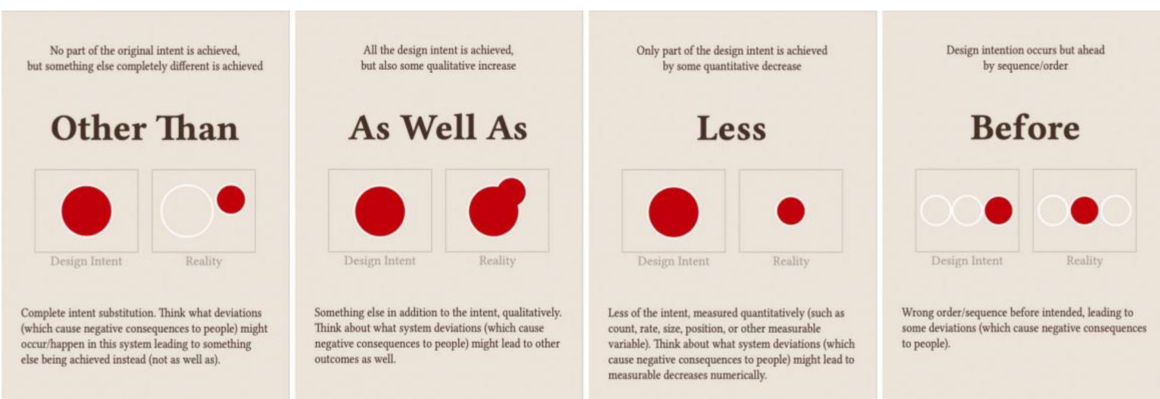

Figure 2: Four example guide word descriptions created (of 13)
(Diagrammatic representations created by authors; text derived from Kletz [25] and extended by authors)

Finally, a short open-ended question online survey was prepared for completion post-workshop, comprising open-ended questions: "*Thinking about one of your own recent projects or studies, how did you identity its potential* *negative consequences, if at all?*", "*What did you like about using this workshop's method to identify negative consequences?*", "*What difficulties arose using this workshop's method?*", "*How do you think this workshop's method could be improved?*", "*What would you need to be able to apply this method in your own work?*" and "*Is there anything else you would like to comment on or suggest?*". The aims of both subsequent pilot studies were twofold: 1) obtain feedback on the HCI HAZOP method; and 2) identify negative consequences for example scenarios describing proposed technology interventions.

5.1.1 Trial Pilot Study: Application to Scenario B (Pre:Peer)

Scenario B was used in the Trial Pilot workshop (the same as for Feasibility Study 2) split into two activities, to be approached 'activity first'. The lead author acted as both *study leader* and *recorder* without contributing to deviation identification. The five participants forming the *study team* were final-year undergraduate computer science students, who had already completed an HCI module and were half-way through an Interaction Design module, and with no prior understanding of the scenario, the social security benefit topic, or HAZOP. A research information briefing sheet was made available and the candidate participants had to confirm their understanding and opt in to participate in the study to continue. The video meeting workshop displayed the *recorder*'s screen showing the four key documents, described above. The *recorder* typed outputs into the record document as they were discussed, described and confirmed by the *study team*, and changed the pages of the documents to reflect the current activity, guide word and, if necessary, tips. Following a brief introduction read from the script, the *study team* were provided with a one-page instruction sheet and a copy of the scenario to examine. The *study leader* led two rounds of applying the standard HAZOP guide words - firstly on the activity of 'gather information' and secondly 'submitting the claim' when needed.

5.1.2 Validation Pilot Study: Application to Scenario C (Ad:Visor)

In the Validation Pilot a different scenario from the authors' other project was used, modified by making it less social security specific. This Scenario C describes 'Ad:Visor', an audio-visual spectacle device worn by citizens seeking assistance, transmitting what is seen and said to a remote advisor. The one-hour Validation Pilot workshop was undertaken independently by new participants (n=5) drawn from HCI researchers and their manager, all known to the authors. The authors took no direct part in the workshop explanation or discussion. One participant agreed to run the workshop and be *study leader*; as someone who had never used HAZOP before they were given a briefing verbally about the method, guide words and scenario, with the opportunity to ask questions and lasting around 45 minutes two days prior to the workshop. The other participants received no briefing or opportunity to ask questions, other than of the *study leader* during the workshop. Based on the Trial Pilot's feedback, the script and supporting documents were shortened, a list of elements/peripheral actors provided, and the *recorder* role undertaken by someone other than the *study leader* and invisibly to the participants. The lead author acted as non-participating *recorder* role during the video meeting (muted and without video). The whole scenario was treated as a single activity, thus requiring one cycle through the guide words. Deviations were captured live during the workshop by the *recorder* and checked and updated immediately afterwards by listening to a recording of the session. This revealed some misunderstandings by the *recorder* and also deviations missed. Participants completed the same follow-up survey as the Trial Pilot. The *study leader* was asked to de-anonymise their own submission since they had been provided with additional background information.

5.2 Findings

5.2.1 Trial Pilot Study Findings: Application to Scenario B (Pre:Peer)

The *study team* identified 44 deviations over 75-minutes (examples in Table 5). Two-thirds of the *study team*'s deviations were different to those identified previously by the lead author in Feasibility Study 1; the overlapping third spanned both activities and most guide words. The *study team* had been asked to focus on harmful consequences to people and a subsequent analysis of deviations, possible causes and consequences tried to categorise the causes by source (e.g., actor, artifact) revealed the majority (32 out of 44) were related to the primary actors - Jo and Kate (26) and the other citizens (8) using Pre:Peer, with the remainder caused by Pre:Peer, other technology, other parties and data ageing.

Table 5: Trial Pilot Study: Example HCI HAZOP Deviations for Scenario B from the perspective of citizens eligible for benefits

Guide word	Deviation	Possible causes	Consequences
NO or NOT	Information submitted not accurate	Human error leading to typos in data entered	Delay to acceptance of submission; incorrect person\/household registered; claim rejected; have to start claim again from scratch; delay to claim start date and payment
	Give up using Pre:Peer system due to effort	Too many steps leading to being overwhelmed	Do not prepare claim; no claim ready to use
	Give up on applying for Universal Credit	Complete all steps to prepare draft claim in Pre:Peer, overwhelmed, but decide UC is too much bother and do something else (e.g., not claim, get better paid/more hours job)	No claim prepared or submitted; change in work situation undertaken that requires more time or effort
REVERSE	Delete a claim instead of making one	Attempt to change a claim and resets to blank; one person in the household had already signed up but not told the other, and their existing claim/award is deleted	Loss of an existing award/payment; deletion of information meaning it has to be added again
AS WELL AS	Make an enemy	Meet or communicated with new people, and now don't get on with them	Mental, physical or financial harm
	Put other people off claiming	Did not like the process and spread negative information about Pre:Peer	Removes Pre:Peer help for other people either by putting them off, or eventually due to the system not being used enough, it is closed down
PART OF	Do not make a joint claim	One person in the household submits an individual claim instead	The single claim has to be cancelled and a joint claim made instead

In the post workshop follow-up survey, the *study team* were asked whether and how they identified negative consequences in their own projects and studies. They mentioned "*assuming worst case scenario for each feature*", looking at a project "*from the point of view of someone else*", how "*a user might use the system... incorrectly*", "*imagine myself using the technologies and what ways I could make it go wrong*". No-one had attempted to do this "*systematically*" previously. When asked what they liked and what they might need to apply it themselves, the *study* *team* noted "*it brought a new, fresh perspective to analyse when it comes to designing or developing something*", "*could be a very useful approach to identify issues*" and was a "*good session overall*", "*enjoyable*", "*really enjoyed it*", "*gave me a lot to think about moving forward with my work*" and would encourage one participant to consider "*how the user might interpret incorrectly*" or how "*just using the system may lead to negative consequences*".

In response to what they liked about the method, one participant noted they were "*surprised how quickly and naturally suggestions came up*", and that the guide words "*meant that there were some quite creative issues brought up*". Another commented that the structured approach "*helped focus my mind*". On the supporting guidance materials one participant "*liked the visualisation and the wording*" on the guide word descriptions. Regarding difficulties, the *study team* felt there was some overlap and ambiguity between the guide words, with some "*much more difficult to give an answer to*" or were *"not applicable in the scenario*" and wanted to know how they were derived (because this was not explained). Two described how they sometimes mistakenly found themselves thinking "*about positive examples instead of negative ones*" with another person saying in some areas it seemed there were "*only positive ones*". In terms of improving the workshop, they would have preferred less introductory explanation, and separation of the *recorder* and *study leader* roles since the documentation of outputs broke the conversation flow while waiting "*to write each thing down*". One wrote "*this method would be better in person when the situation allows it*" and that including additional people with other viewpoints and experiences "*would have resulted in even more useful information*" and make "*sure all areas were explored*". The lead author had similarly noted participants' questions revealing a lack of knowledge about the scenario and its wider context, which would not be usual in traditional HAZOP.

5.2.2 Validation Pilot Study Findings: Application to Scenario C (Ad:Visor)

65 distinct deviations were identified during the 50-minute examination. The four-member *study team* defined a more evenly balanced range of deviations across the guide words than in the Trial Pilot (different team and different scenario). Analysis revealed many deviations (37 out of 65) had causes related to the primary actors – citizen Sarah (23) and the advice agency (14), and a large number identified as caused by Ad:Visor itself (25), with the remainder by other parties (3). The study team explicitly referred to their own experiences with other devices such as "*remember ... when we worked on the ... devices we had to reconfigure them...*" and "*charging them is not easy*" (NO or NOT). Some deviations were inherent to the activity rather than only possible because of the technology interventions e.g., "*Other advice matter identified*" (AS WELL AS). A few examples demonstrating the range of deviations are shown in Table 6.

Table 6: Validation Pilot Study: Example HCI HAZOP Deviations for Scenario C from the perspective of citizen seeking advice

Guide word	Deviation	Possible causes	Consequences
AS WELL AS	Other visual information shared	Camera observes other aspects of citizen's life wherever citizen looks which gets transmitted to advisor; citizens accidentally looks at something else	Loss of privacy
	Fatigue	Spend more time staring at phone and documents	Eye strain; migraine; do not complete call
	Other advice matter identified	Discussion leads to advisor identifying other issues that need	Left with another problem to deal with

Guide word	Deviation	Possible causes	Consequences
		addressing/affect the citizen which they did not know about	
	Hear other people's calls through the device	Crossed calls	–
	Immediate danger revealed	Advisor sees something dangerous in the camera image and needs to decide whether to call emergency services / report it	Moral burden on advisor to make decision - if not reported the citizen may at risk of harm; if they do report some other things that may have other negative consequences on the family too

Despite the expectation Scenario C would be familiar, the *recorder* noted there was still difficulty for some participants in three areas: conceptualising the digital intervention described in the scenario (which the *study leader* did address during the workshop), thinking of interaction deviations when the type of advice being provided was not specified, and confusion related to overlaps and contradictions between overall activity intent with individual action intents. Participants' responses to the follow-up survey question about what existing practices they, as experienced researchers, used to discover negative consequences included participatory design approaches where users were asked downsides or using a "*provocative statement or scenario to stimulate reflection*", issue lists, researcher's own identification of failures and consequences, usability testing with think aloud, and reflections based on experience. When asked about the HCI HAZOP method itself, inexperience with the method was highlighted: "*difficult to know the scope of what was being asked*", "*difficulties in conceptualizing the method's questions*" and "*took me a while to really understand what I though[t] they meant*" - the *study leader* added "*the guide words are really difficult to apply, especially REVERSE*". This contributed to a feeling from one person that there was a need for "*more time in trying to understand each question and respond within its frame, rather than brainstorm on deviation*" and from another that the shared discussion and time-limited session reduced the ability to "*focus... while listening to other participants*". The *study leader* commented on the considerable effort to "*constantly working out - is that a deviation, is it a cause, is it a consequence*" and to maintain the required independent stance "*not to prompt them*". The feedback also highlighted unfamiliarity with the scenario and technology e.g., the difficulty "*contextualizing to specific contexts*", needing the scenario to be "*a bit more specific with regards to context of use*" and "*if we really were part of the project we would be immersed in it and it would come more naturally*". When asked what would be needed to use the method in their own research, something to address the initial "*steep entry/brain engagement*" was again raised, as well as a need for more thinking time, source materials and a platform for recording outputs. One of the *study team* noted that if a study team included people from the wider "*general public*", there would be an even greater need to "*translate the method*", and have other "*prompts*" as well as allowing much more time for an equivalent scope. One participant "*would need to see it used more and understand how I could use it*" with another mentioning how it might help diversify people's considerations: "*I think I can benefit from using this method because it frames the thinking of participants well, and therefore helps in addressing different aspects without getting anchored in a certain problem area in the whole workshop*". In terms of what they liked, individual participants mentioned "*the sequence of [guide word] prompts*", how the method identifies "*consequences that I would never have thought of so it is useful*", "*it really narrowed down and framed the participant's thought space - which is useful for the researcher*", "*quite creative*" and the "*speculative questions to prompt responses*".

6 DISCUSSION

Beginning with a summary of how HAZOP was adapted for use in an HCI context, we then discuss three topics describing changes implemented from experience applying the method: deviation identification, scope coverage and guide words. We then present a summary of how to apply HCI HAZOP and conclude with an explanation of how the authors have already used the studies' identified deviations.

6.1 From HAZOP to HCI HAZOP

The inductive HAZOP guide word method has been adapted for a HCI context and updated iteratively through the four studies presented. The modifications are a) considering harm impacts from the perspective of the people involved, rather than assets more generally; b) foregrounding people as contributing actors, rather than as sources of system errors c) recognising and considering influences from and effects on other elements in the socio-technical system including those over which there is little control and can change over time, rather than a more controlled environment d) creating HCI-specific guide word descriptions and novel diagrammatic representations; and e) reordering the typical guide words and merging of four chronological guide words into two (see 6.4), to reflect more human-specific deviations and improve comprehension. HCI HAZOP's more people-centric approach considers a wider range of harmful effects that individuals and communities might perceive or suffer, requires the *study team* to be representative and include appropriate knowledge and experience spanning the wider socio-technical system, and notably unlike HAZOP it does not expect to enumerate all deviations (see 6.3).

6.2 Deviation identification

The Trial Pilot notably identified additional deviations which had not been revealed during Feasibility Study 2 despite the lead author being an expert in Scenario B's context and technology intervention, and the HAZOP method itself. Five undergraduate students without any prior experience of the methodology were able to contribute to the process, despite only having introductory knowledge of other HCI techniques. None of the studies exhausted each team's capacity to identify deviations, and were instead limited by workshop time allocation including opportunity for reflection.

Deviations, their causes, and consequences were not always differentiated correctly, and this led to extra time adjusting and updating the recorded outputs. HAZOP is a systematic method; the studies indicate that untrained practitioners could very easily move away from the prescribed method, such as by identifying consequences or causes first rather than starting from deviations. This seemed to be partly due to unfamiliarity with the guide words, compounded by having less familiarity with the technical interventions described in the scenarios which led to some confusion over what the design intents were. In both pilots, people mistakenly mentioned some positive consequences (in AS WELL AS) which were challenged and revised into closely related negative ones. The *study leader* in each of the pilots used their own skills to keep the method on track as much as possible, with this becoming less of a problem as each workshop progressed. The authors had been reluctant to introduce too many layers of analysis into the method (i.e., looping potentially through every action and element), and created tips on motivations/situations for the Trial Pilot, but these were not used. Similarly, in the Validation Pilot, a list of elements within the activity and actions provided was not referred to explicitly. Adding more structure may extend examination duration, but this does suggest that individual citizens and community members who should be part of the *study team* members will be able to add value despite having none or no experience of the method.

6.3 Scope coverage

Outputs from the Trial Pilot indicated a greater focus on actions by primary actors, and less on accidental or malicious misuse by other actors and artifacts. This could reflect that it is easier to imagine oneself in those roles, or maybe the relative inexperience of the *study team* because there were better balanced outputs in the Validation Pilot involving much more experienced researchers. Traditional HAZOP is reliant on the knowledge and experience of the team members [12,45,51] and HCI HAZOP is no different. It requires collaboration from a diverse range of study participants so that all their combined experience, knowledge, imagination, values and biases contribute. The intention in HAZOP is to identify and mitigate all deviations [25]. The findings from HCI HAZOP suggest the multi-various deviations possible in broader socio-technical systems, where people have varying norms and rules and there are potentially more external actors who can influence the system, mean that the objective can never be to identify all deviations. Potential deviations will change over time as knowledge and technology changes; the risks are not static. Consequently, multiple examinations of the same socio-technical activity by different study teams is likely to produce different outputs and give no clear idea of how complete the identification of deviations is. This may not be a downside if the purpose is to contribute extra knowledge to research by design projects, but it must be made clear that harm identification is not complete, and that if a greater coverage is required, this may require smaller scope, and/or longer time. As coverage increases, output reproducibility by different study teams with similar knowledge and experience may increase.

6.4 Guide words

The pilot studies still indicated difficulties with grasping the meaning of the guide words, with the resulting pilot workshops being less systematic in the process. Despite this, study participants did enumerate many useful deviations highlighting limitations and concerns with technologies, without any prior methodological experience or training which is itself contrary to traditional HAZOP where "*either all team members should have sufficient knowledge of the HAZOP methodology to enable them to participate effectively in the study, or suitable training should be provided*" [21]. The guide word ordering change, implemented after Feasibility Study 1 was noted as improving subsequent examinations and did not lead to any other problems. The chronological guide words (see Table 2) tended to reveal fewer deviations, and participants has some difficulties distinguishing between these e.g., in an interaction between two actors early for one, is late for another. Replacing all four by two different guide words 'ORDER' and 'TIME' is recommended. Overall, like work on human factor HAZOP by Ellis and Holt [13] and Aspinall [2], it was found the standard guide words were otherwise suitable and sufficient for HCI focused HAZOP, with 'OTHER THAN' and 'REVERSE' more problematic to grasp suggesting a revised sequence could improve results. The method's latest materials reflect this and the chronological alternatives, to become 'ORDER, TIME, AS WELL AS, MORE, PART OF, LESS, NO or NOT, OTHER THAN, REVERSE'. A benefit of the method is that as long as deviations are identified, it does not matter which guide word motivated them.

6.5 Examination approach and summary

The study outputs and feedback point to opportunities to customise the method for varying design fidelity, activity scope, as well as harm perspective. The 'activity first' approach was found to be sufficient at earlier stages of design where prototypes are less developed, or where the aim is to use HCI HAZOP as a screening method between design choices. Concepts and incomplete designs can be problematic in traditional HAZOP [45,51], but in research by design, exploration of technology and intent could be the objective. With greater design definition, there may be a need to narrow the scope from activities to their actions (sub-activities) and consider additionally systematically working through other elements for greater deviation coverage, at a cost of longer examinations. These and other matters need to be confirmed during the study's definition step; a summary of this and the updated HCI HAZOP method is provided in Figure 3, using the generic term 'item' which could be 'activity', 'action' or some other element type within the socio-technical system's scope to suit the assessment objectives.

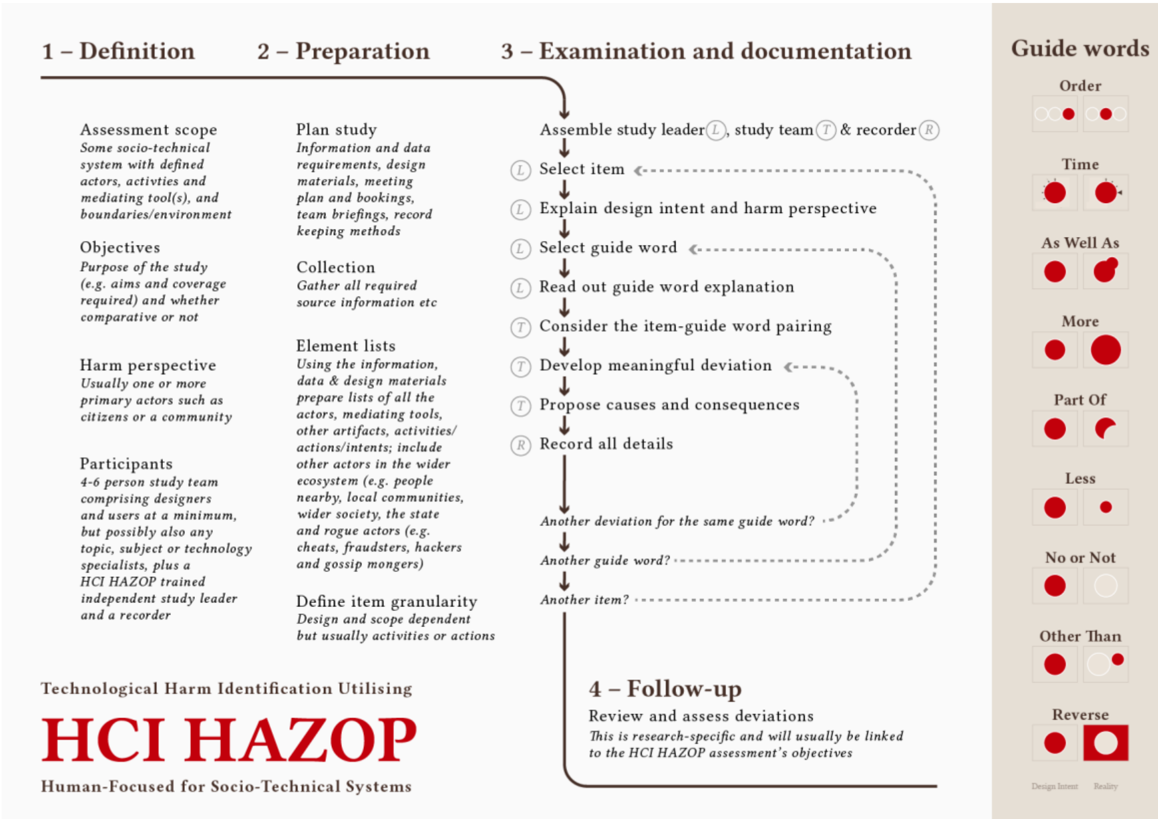

Figure 3: Diagrammatic overview of the finalised four-step HCI HAZOP methodology

6.6 HCI HAZOP and SBD

The methodology was applied and developed using existing scenarios. The downside of this was that the *study teams* in the pilot studies did not have any real knowledge or experience of the issues being addressed by, nor of the technology intervention itself. Since HAZOP [43] like SBD [36] is not design-neutral - both rely on the participant's vision, knowledge and experience, along with their expectations and biases – it is not clear yet how this affected the deviations identified. The spread of deviations across the last three studies indicate individuals were contributing in their own ways. In terms of the SBD Framework, the exploration of deviations using HCI HAZOP could contribute to requirements analysis, activity design, information design, interaction design and usability evaluation. Given the framework is iterative, this could begin with broader examinations of earlier designs that contribute to their development and comparison, and as designs become more defined and with greater fidelity, HCI HAZOP could examine activities and actions in greater depth to add further value. For between scenario comparisons, deviations in each option should be checked for existence in the other options, if not already identified.

Returning to the original motivation for this methodology's development, the studies described in this paper catalogued a large number of problematic deviations for two of the other project's digital intervention scenarios. These were used directly and ranked by impact on social security claimants and public awareness. Three deviations with greater impact and lesser awareness have been used to create problem vignettes for each scenario (for Scenario B shown in Figure 4). Further scenarios were treated similarly. The HCI HAZOP-sourced problem vignettes are now being used as provocations during interviews with Universal Credit claimants in the other project.

Figure 4: Problem Vignettes created from ranked HCI HAZOP sourced deviations for Scenario B
(Component images open source and public domain – attributed fully in supplementary materials)

7 LIMITATIONS AND FUTURE WORK

We acknowledge the experience of using the adapted method is based on two limited pilot studies, but including a validation pilot where authors took no active part. Although the *study teams* in both pilots did not have the method's expected knowledge and experience of either HAZOP or the designs being assessed, the deviation outputs provided significant findings about undesirable consequences on citizens by two different digital interventions. Participants were drawn from a single institution and therefore, despite their citizen-centric HCI backgrounds, the workshops did not include representatives from the range of relevant actors, and needs to be pursued in further trials. HAZOP itself imposes a focus on discrete deviations [21] and it is believed this could be more problematic in socio-technical systems if combinations of these [11] have significant adverse impacts on people. It is not clear how to counter this, but it could possibly be addressed by a design-led review of the aggregated outputs in the follow-up step, and should be investigated.

Other further work is required to gather experience using design materials other than scenarios, such as from later stages of prototype design. Additionally, the authors want to develop some HCI HAZOP learning materials providing study team members with practice using the guide words in pre-study training. This would then permit two supplemental stages: further studies by other researchers themselves on their own projects, and studies involving non-researcher study team members. Future work is also needed to explore how to support consideration of actors' confusion, disgust, irritation, anger, frustration, annoyance – potential experiential harms.

8 CONCLUSION

In this paper we have presented an adaption of the HAZOP guide word method to use in a HCI context for socio-technical systems where contributions by, and harms to, are foregrounded. Experience from applying the method in two feasibility studies and two pilot studies using scenario-based design artifacts as source materials provided insights used to update the technique, and identify limitations and benefits. Overall, we have demonstrated that HCI HAZOP is a practical method to help identify issues that affect technology adoption and sustainability. We have provided recommendations and guidance materials for use by other researchers.

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REFERENCES

[1] John Annett. 2003. Hierarcical Task Analysis. In E. Hollnagel, ed., *Handbook of Cognitive Task Design*. Lawrence Erlbaum Associates, 17–35.

[2] P. Aspinall. 2006. HAZOPs and human factors. *HAZARDS XIX – Process Safety and Environmental Protection Symposium*, Institution of Chemical Engineers.

[3] Liam J Bannon. 1991. From Human Factors to Human Actors: The Role of Psychology and Human-Computer Interaction Studies in System Design. In J. Greenbaum and M. Kyng, eds., *Design at Work: Cooperative Design of Computer Systems*. CRC Press.

[4] Eric P S Baumer and M Six Silberman. 2011. When the Implication is Not to Design (Technology). *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery, 2271–2274.

[5] P Baybutt. 2002. Layers of Protection Analysis for human factors (LOPA-HF). *Process Safety Progress* 21, 2: 119–129.

[6] Stuart K Card, Allen Newell, and Thomas P Moran. 1983. *The Psychology of Human-Computer Interaction*. L. Erlbaum Associates Inc., USA.

[7] John M Carroll. 1999. Five Reasons for Scenario-Based Design. *Proceedings of the Thirty-Second Annual Hawaii International Conference on System Sciences-Volume 3 - Volume 3*, IEEE Computer Society, 3051.

[8] John M Carroll and Mary Beth Rosson. 1992. Getting around the Task-Artifact Cycle: How to Make Claims and Design by Scenario. *ACM Trans. Inf. Syst.* 10, 2: 181–212.

[9] Francis Dittoh, Hans Akkermans, Victor de Boer, Anna Bon, Wendeline Tuyp, and Andre Baart. 2020. Information Access for Low-Resource Environments. *Proceedings of the 3rd ACM SIGCAS Conference on Computing and Sustainable Societies*, Association for Computing Machinery, 325–326.

[10] Alan Dix, Janet Finlay, Gregory D Abowd, and Russell Beale. 2016. *Human-Computer Interaction Third Edition*. Pearson.

[11] J Dunjó. 2010. New trends for conducting hazard & operability (HAZOP) studies in continuous chemical processes. Retrieved from https://dialnet.unirioja.es/servlet/tesis?codigo=85277.

[12] Jordi Dunjó, Vasilis Fthenakis, Juan Vilchez, and Josep Arnaldos. 2009. Hazard and operability (HAZOP) analysis. A literature review. *Journal of hazardous materials* 173: 19–32.

[13] G Ellis and A Holt. 2009. A Practical Application of 'Human-HAZOP' for Critical Procedures. .

[14] Robert Fields, Fabio Paternò, Carmen Santoro, and Sophie Tahmassebi. 1999. Comparing Design Options for Allocating Communication Media in Cooperative Safety-Critical Contexts: A Method and a Case Study.

ACM Trans. Comput.-Hum. Interact. 6, 4: 370–398.

[15] John Gould, Michael Glossop, and Agamemnon Ioannides. 2000. *HSL/2005/58 Review of Hazard Identification Techniques*. HM Government.

[16] Jan Gugenheimer, Mark McGill, Samuel Huron, Christian Mai, Julie Williamson, and Michael Nebeling. 2020. Exploring Potentially Abusive Ethical, Social and Political Implications of Mixed Reality Research in HCI. *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery, 1–8.

[17] Marilys Guillemin and Lynn Gillam. 2004. Ethics, Reflexivity, and "Ethically Important Moments" in Research. *Qualitative Inquiry* 10: 261–280.

[18] Kevin Haggerty. 2004. Ethics Creep: Governing Social Science Research in the Name of Ethics. *Qualitative Sociology* 27: 391–414.

[19] Health and Safety Executive. *Core Topic 3: Identifying human failures*. HM Government.

[20] Health and Safety Executive. Human factors: Managing human failures. *gov.uk*. Retrieved 5 March 2021 from https://www.hse.gov.uk/humanfactors/topics/humanfail.htm.

[21] International Electrotechnical Commission. 2016. *IEC 61882:2016 Hazard and operability studies (HAZOP studies) - Application guide*. International Electrotechnical Commission.

[22] Victor Kaptelinin and Bonnie A Nardi. 2006. *Acting with Technology: Activity Theory and Interaction Design*. The MIT Press.

[23] Brian C Keegan and J Nathan Matias. 2015. *Actually, It's About Ethics in Computational Social Science: A Multi-party Risk-Benefit Framework for Online Community Research*. .

[24] B Kirwan and L K Ainsworth. 1992. *A Guide to Task Analysis*. Taylor & Francis.

[25] Trevor Kletz. 1999. *Hazop and Hazan: Identifying and assessing process industry hazards*. Institution of Chemical Engineers.

[26] Trevor Kletz. 2001. *An Engineer's View of Human Error*. CRC Press.

[27] Trevor Kletz, Paul Chung, Eamon Broomfield, and Chaim Shen-Orr. 1995. *Computer Control and Human Error*. Gulf Professional Publishing.

[28] J C Knight. 2002. Safety critical systems: challenges and directions. *Proceedings of the 24th International Conference on Software Engineering. ICSE 2002*, 547–550.

[29] Masaaki Kurosu, Kentaro Go, Naoki Hirasawa, and Hideaki Kasai. 2007. Micro-Scenario Database for Substantializing the Collaboration Between Human Science and Engineering. 140–145.

[30] H G Lawley. 1974. Operability Studies and Hazard Analysis. *Loss Prevention Symposium* 8: 105–116.

[31] Damien Martin-Guillerez, Jérémie Guiochet, David Powell, and Christophe Zanon. 2010. A UML-based method for risk analysis of human-robot interactions. *Proceedings of the 2nd International Workshop on Software Engineering for Resilient Systems, SERENCE 2010*.

[32] Róisín McNaney and John Vines. 2015. Blurred Lines: A Reflection on the Ethical Dilemmas Encountered during the 'Google Glass for Parkinson's' Project. *CHI 2015 workshop 'Ethical Encounters in HCI: Research in Sensitive Settings'*. Retrieved from http://dx.doi.org/10.13140/RG.2.1.1204.6888.

[33] Cosmin Munteanu, Heather Molyneaux, and Susan O'Donnell. 2014. Fieldwork with Vulnerable Populations. *Interactions* 21, 1: 50–53.

[34] Lisa P Nathan, Batya Friedman, Predrag Klasnja, Shaun K Kane, and Jessica K Miller. 2008. Envisioning Systemic Effects on Persons and Society throughout Interactive System Design. *Proceedings of the 7th ACM Conference on Designing Interactive Systems*, Association for Computing Machinery, 1–10.

[35] Lisa P Nathan, Predrag V Klasnja, and Batya Friedman. 2007. Value Scenarios: A Technique for Envisioning Systemic Effects of New Technologies. *CHI '07 Extended Abstracts on Human Factors in Computing Systems*, Association for Computing Machinery, 2585–2590.

[36] Fabio Paterno and Carmen Santoro. 2002. Preventing user errors by systematic analysis of deviations

from the system task model. *International Journal of Human-Computer Studies* 56, 2: 225–245.
[37] Lucy Pei and Roderic Crooks. 2020. Attenuated Access: Accounting for Startup, Maintenance, and Affective Costs in Resource-Constrained Communities. *CHI '20: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*.
[38] Lucy Pei and Bonnie Nardi. 2019. We Did It Right, But It Was Still Wrong: Toward Assets-Based Design. *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery, 1–11.
[39] Peter G Polson, Clayton Lewis, John Rieman, and Cathleen Wharton. 1992. Cognitive walkthroughs: a method for theory-based evaluation of user interfaces. *International Journal of Man-Machine Studies* 36, 5: 741–773.
[40] B Rasmussen and C Whetton. 1997. Hazard identification based on plant functional modelling. *Reliability Engineering and System Safety* 55, 2: 77–84.
[41] J. Reason. 1995. Understanding adverse events: human factors. *Quality in health care : QHC*.
[42] Mary Beth Rosson and John M Carroll. 2002. Scenario-Based Design. In *The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications*. 1032–1050.
[43] Donald L Schurman and Stephen A Fleger. 1994. Human factors in HAZOPs: Guide words and parameters. *Professional Safety* 39, 12: 32.
[44] Robert Soden, Michael Skirpan, Casey Fiesler, et al. 2019. CHI4EVIL: Creative Speculation on the Negative Impacts of HCI Research. *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery, 1–8.
[45] C D Swann and M L Preston. 1995. Twenty-five years of HAZOPs. *Journal of Loss Prevention in the Process Industries* 8, 6: 349–353.
[46] Emily Tseng, Rosanna Bellini, Nora McDonald, et al. 2020. The Tools and Tactics Used in Intimate Partner Surveillance: An Analysis of Online Infidelity Forums. Retrieved from https://arxiv.org/abs/2005.14341.
[47] Christopher J Vincent and Ann Blandford. 2015. Usability standards meet scenario-based design: Challenges and opportunities. *Journal of Biomedical Informatics* 53: 243–250.
[48] Colin Watson, Reuben Kirkham, and Ahmed Kharrufa. 2020. PIP Kit: An Exploratory Investigation into using Lifelogging to support Disability Benefit Claimants. *CHI '20: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*.
[49] Jenny Waycott, Greg Wadley, Stefan Schutt, Arthur Stabolidis, and Reeva Lederman. 2015. The Challenge of Technology Research in Sensitive Settings: Case Studies in 'Ensitive HCI'. *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction*, Association for Computing Machinery, 240–249.
[50] Jens H Weber and Morgan Price. 2016. Closing the Gap: Enacting Knowledge Transfer between Engineering and Use of Healthcare Software. *Proceedings of the International Workshop on Software Engineering in Healthcare Systems*, Association for Computing Machinery, 19–25.
[51] S Whitty and T Foord. 2009. Is HAZOP worth all the effort it takes? 143–148.
[52] Norbert Wiener. 1948. *Cybernetics or Control and Communication in the Animal and the Machine*. MIT Press.
[53] Norbert Wiener. 2018. *God & Golem, Inc.* MIT Press.
[54] Richmond Y Wong, Vera Khovanskaya, Sarah E Fox, Nick Merrill, and Phoebe Sengers. 2020. Infrastructural Speculations: Tactics for Designing and Interrogating Lifeworlds. *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery, 1–15.
[55] O Zendel, K Honauer, M Murschitz, M Humenberger, and G Fernández Domínguez. 2017. Analyzing computer vision data - The good, the bad and the ugly. *Proceedings - 30th IEEE Conference on Computer Vision and Pattern Recognition, CVPR 2017*, 6670–6680.

[56] Oliver Zendel, Markus Murschitz, Martin Humenberger, and Wolfgang Herzner. 2015. CV-HAZOP: Introducing Test Data Validation for Computer Vision. *2015 IEEE International Conference on Computer Vision (ICCV)*.