A Comparison of Incident Investigation Outcomes and Safety Recommendations between Clinical Safety and AcciMap Experts

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This paper focuses on the perception of Branford's standardized AcciMap approach as a tool for accident analysis in healthcare. This study further builds on the previous work regarding National Health Service (NHSScotland) clinical safety practitioners' first-time experience in applying the standardized AcciMap approach, and discusses its advantages and limitations [Ref. 1]. A series of training sessions were carried out with a clinical domain expert from the National Services Scotland (NSS) to apply the standardized AcciMap approach for health information technology (IT) analysis. The AcciMap method was used to analyze a medication error incident involving the computerized provider order entry (CPOE) system [Ref. 2] by Clinical and AcciMap experts. Outcomes and safety recommendations from both participants were then qualitatively compared and discussed to gain further insight into applying the AcciMap method.

Introduction

Incident/accident investigation and analysis helps to support safety management to improve safety and quality of service [Refs. 3, 4 and 5]. These essential activities are employed across various safety-critical industries to detect and mitigate risks to the safety of people, assets, and organizations. Within healthcare systems, safety practitioners have more commonly used root cause analysis (RCA) approaches than the recent systemic accident analysis (SAA) approaches [Ref. 6]. Particularly with this study, the use of health information technology (comprising both software and hardware) has played a crucial role in improving the safety of patients [Refs. 7, 8, 9 and 10]. However, implementing and using health IT has added another layer to an already complex socio-technical system like healthcare, which can potentially cause unintentional consequences [Refs. 2 and 11]. For example, using a computerized provider order entry system (CPOE) can create new risks that can ultimately compromise patient safety, eventually leading to patient death and affecting the health organization's reputation [Refs. 12 and 13].

Various systemic accident analysis (SAA) approaches like STAMP (system theoretic accident and modelling process [Refs. 14 and 15] and FRAM (functional resonance accident model) [Ref. 16] can help practitioners conduct a deeper analysis of software-related incidents [Refs. 17 and 18]. This process includes not only identifying causal/contributing factors (actions/decisions) at the frontline, but also weaknesses in the system both within and outside (organizational and external) of health organizations. The study applies the standardized AcciMap approach [Ref. 19] to a health-IT-related case incident and compares results between safety experts from different domains. The following sections and sub-sections briefly describe the AcciMap method, incident analysis and their AcciMap results (contributing factors, causal links and safety recommendations). Then, these results are compared for similarities and variations.

The Standardized AcciMap Approach

This AcciMap version was developed by Branford in her thesis, which investigated its validity and reliability [Ref. 19] and is based on the original AcciMap format [Refs. 20, 21 and 22}. It consists of four different levels of analysis — outcomes; physical/actor events, processes, and conditions; organizational; and external (see Figure 1). A set of guidelines was also developed in association with the method to help analysts apply causal analysis in modelling AcciMap outputs and formulate safety recommendations [Refs. 19 and 23].

Study Objectives

In determining the suitability of the standardized AcciMap approach as an alternative to RCA techniques for health IT analysis, the following objectives were undertaken in this study:

1. Comparing AcciMap outcomes and safety recommendations between clinical safety and AcciMap experts for similarities and differences.

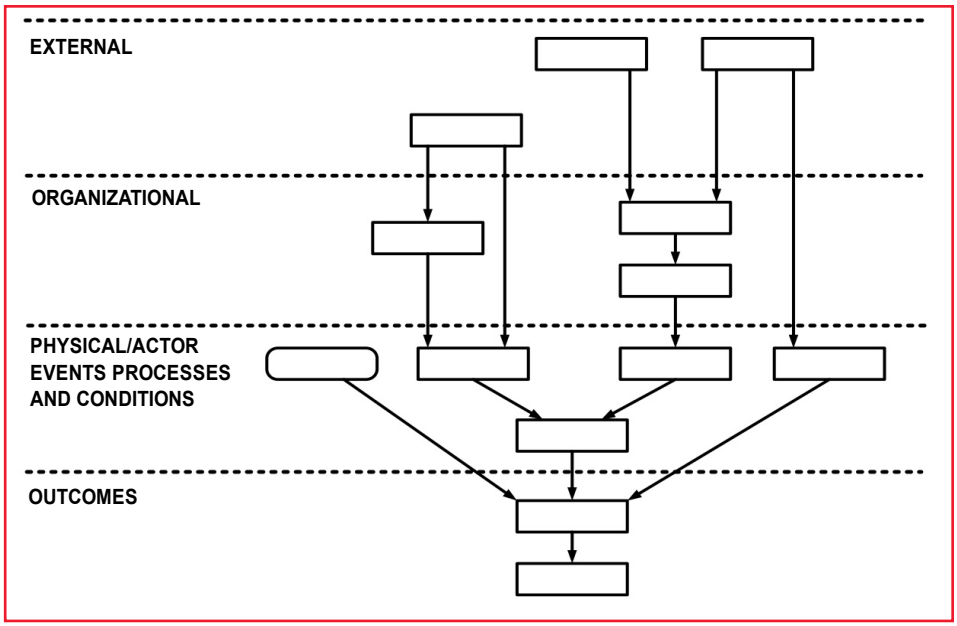

Figure 1 — The Standardized AcciMap method [Refs. 19 and 20].

2. Determining if Branford's standardized AcciMap method is more beneficial than RCA techniques for incident analysis based on the clinical safety expert's first-time experience.

Research Methodology

A qualitative (case study) approach was adopted to analyze an IT-related case incident (medication dosing error) using the standardized AcciMap method and compare findings between the two experts. The following sub-sections briefly highlight the methods used for this study.

Participants

Two participants, designated as Analyst A (clinical domain expert) and Analyst B (AcciMap expert), participated in the study. Analyst A is a clinical safety officer and e-pharmacist with more than 25 years of experience in health informatics, in addition to five years of safety auditing with the National Services Scotland (NSS). Analyst B (expert) is an experienced human factors specialist with extensive knowledge and experience in human factors engineering and accident analysis approaches. The second participant (AcciMap expert) also developed the standardized AcciMap method and associated guidelines for causal analysis.

Training Provided

AcciMap training sessions were organized with the clinical expert, with each training/discussion session lasting between two to three hours. The clinical safety expert was introduced to the concept of systems thinking and to Branford's AcciMap approach. Example incidents [Refs. 24 and 25] were also provided for the participant in applying the AcciMap guidelines and were reviewed during training sessions before using it on the CPOE medication error incident.

Study Design

The case incident (medication dosage error) was used as the last incident for the AcciMap analysis. Information on safety recommendations or lessons learned from the initial documentation was omitted to reduce bias. Both experts applied the standardized AcciMap method and were instructed to focus only on the information available and avoid making any inferences (not supported by evidence from the case report). Outcomes from both experts were then compared for similarities and variations (content validity). This approach was utilized based on Branford's study, which argued that in the absence of the "gold standard" to measure the validity of the results, the best alternative approach would be to compare with "expert" analysis [Ref. 19]. Safety recommendations produced by each expert were also compared. Finally, AcciMap results were then swapped between both analysts through email correspondence and reviewed. This process allowed the AcciMap expert to assess the clinical expert's AcciMap outputs regarding causal/contributing factors, placement, causal links between factors and safety measures. After the exercise, the clinical expert was subsequently interviewed on his perception of the AcciMap approach in the final session.

AcciMap Analysis of the CPOE Medication Error Incident

The case incident involved two clinical providers (A and B) involved in the administration of potassium choloride (KCl) using a computerized provider order entry (CPOE) system to a patient who was initially hypokalemic [Ref. 2]. Events and decisions made by both providers eventually led to the patient being administered a high dose of KCl and becoming hyperkalemic. These events took place over three days; the accident was ultimately detected, and the patient was subsequently treated. Appendix (A-1) details the timeline of events.

As detailed in the previous "Study Design" subsection, after the clinical expert (Analyst A) finished training, each expert independently analyzed the CPOE medication error incident and returned their respective AcciMap results after about a week. The clinical expert (Analyst A) produced the AcciMap output, as shown in Figure 2. The AcciMap expert (Analyst B), based in Australia, developed an initial AcciMap model of the incident, but subsequently re-analyzed the work to produce the final version (see Figure 3) along with safety recommendations. Both AcciMap outcomes were compared for any similarities and variations regarding their analysis (see the "Study Design" subsection). Finally, Analyst B's AcciMap result

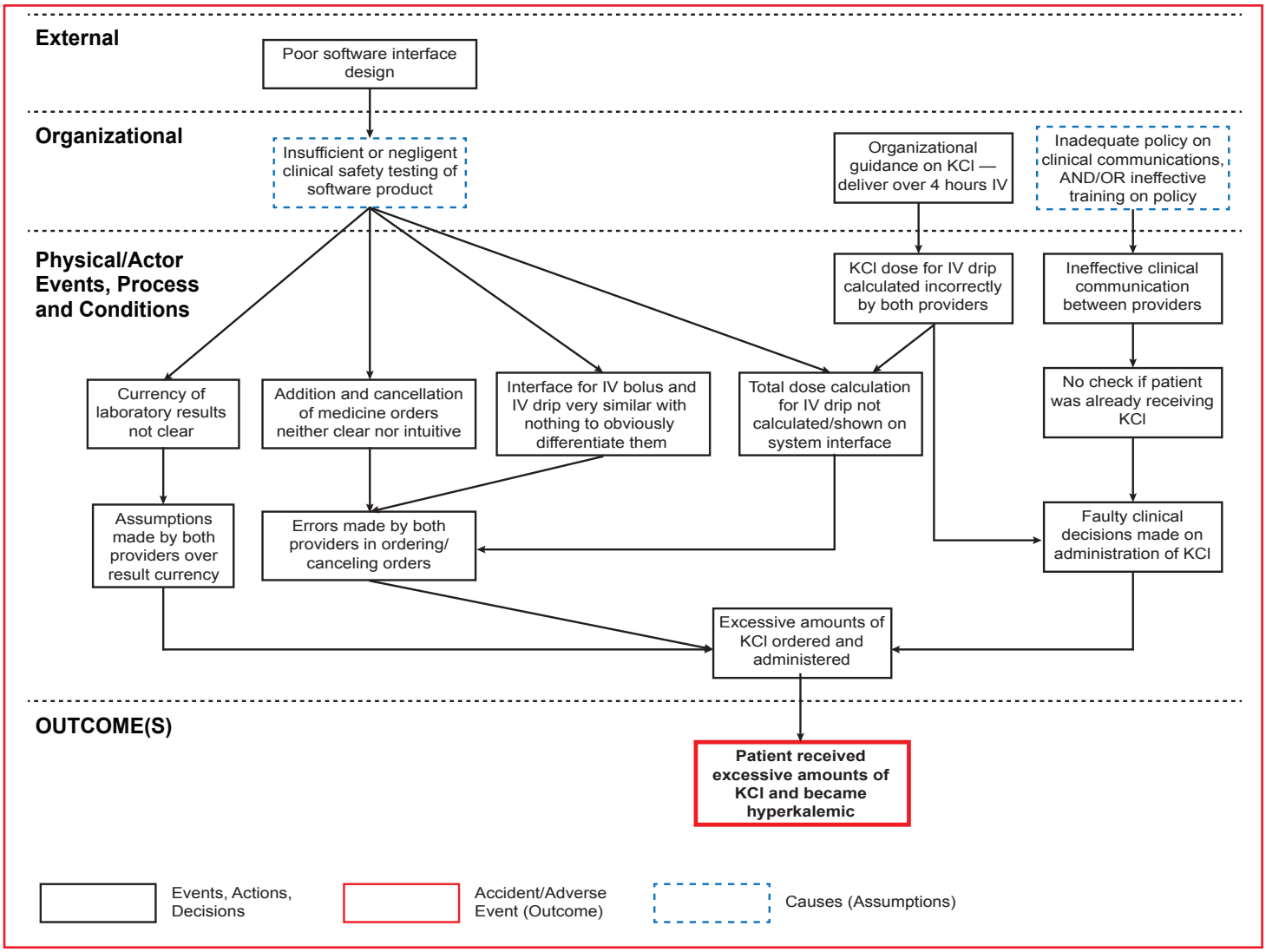

Figure 2 — AcciMap Analysis of Analyst A (Clinical Safety Expert).

served as the alternative standard in the absence of a gold measurement standard.

Results

After both experts completed their analyses, content analysis was applied to qualitatively identify similar themes regarding causal/contributing factors, placement of these factors and causal links between them. Also, an interview session took place after the exercise so the clinical safety expert could obtain feedback regarding the experience applying the AcciMap method.

Comparison between Analyst A and Analyst B

The AcciMap results produced by both experts were compared based on different aspects as identified in Branford's thesis and explained in the proceeding subsection as follows:

1. Identification of contributing factors
2. Placement of contributing factors at the appropriate AcciMap level
3. Causal links between contributing factors
4. Safety recommendations

Identification of Contributing Factors — Contributing factors identified by both experts were denoted as solid boxes. Other contributing factors indicated as broken boxes (inferences) were not considered for comparative purposes. Both experts identified similar and varying causal/contributing factors for each AcciMap level. For example, based on the AcciMap outputs in Figure 4, similar contributing factors identified by both experts related to issues including miscommunication between both providers, assumptions regarding the KCl value, and errors regarding ordering and the cancellation of orders. From the content analysis, contributing factor themes (C1, C2, and C3) relating to how clinical providers A and B interacted with the CPOE system are also denoted in Table 1. The remaining contributing factor themes (C4, C5, and C6) regarding errors committed by both providers are also detailed in Table 1. From both diagrams, there are instances where the clinical expert (Analyst A) identified a contributing factor is similarly recognized by the AcciMap expert (Analyst B). For example, the clinical expert (Analyst A) made two distinct causal/contributing factor boxes relating to CPOE issues, specifically regard-

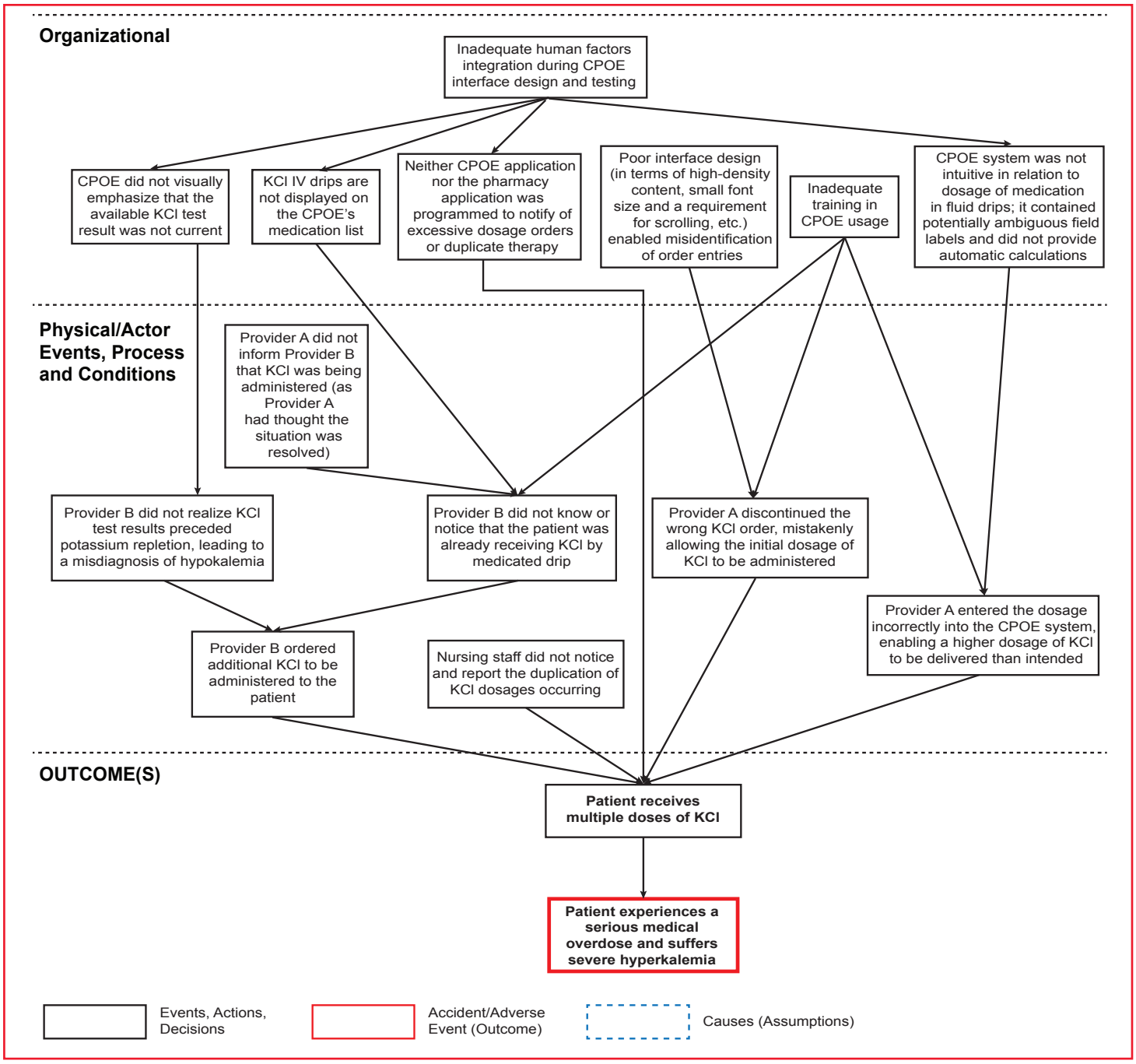

Figure 3 — AcciMap Analysis of Analyst B (AcciMap Expert).

ing not being intuitive and not incorporating automatic calculations (C2), which Analyst B identified as a singular factor. However, these contributing factor boxes convey the same meaning to the contributing factor identified by Analyst B when combined into a single factor.

Another contributing factor theme (C3) identified as a distinct factor by the clinical expert (relating to both providers making errors regarding ordering and cancelling) was recognized by the AcciMap expert as two separate contributing factor boxes but when combined, also convey a same meaning.. However, those factors focused on the errors made by Provider A only (AcciMap expert). Table 2 details contributing factors that were uniquely identified by each expert based on their respective AcciMap model outputs.

Placement of Contributing Factors — Branford noted the importance of placing causal/contributing factors at the appropriate AcciMap level to identify parties responsible for implementing safety recommendations. In the results shown in Figure 5, contributing factors denoted as red boxes indicate differences in the placement of contributing factors between both experts. For instance, when comparing the placement of contributing factors related to the CPOE system, C1 and C2, Analyst A identified and placed these factors at the physical/actor activities level, while Analyst B associated them at the organizational level. However, the other contributing factor theme, C3, was placed by both participants at the physical/actor level. Therefore, regardless of the differences in the placement of contributing factors relating

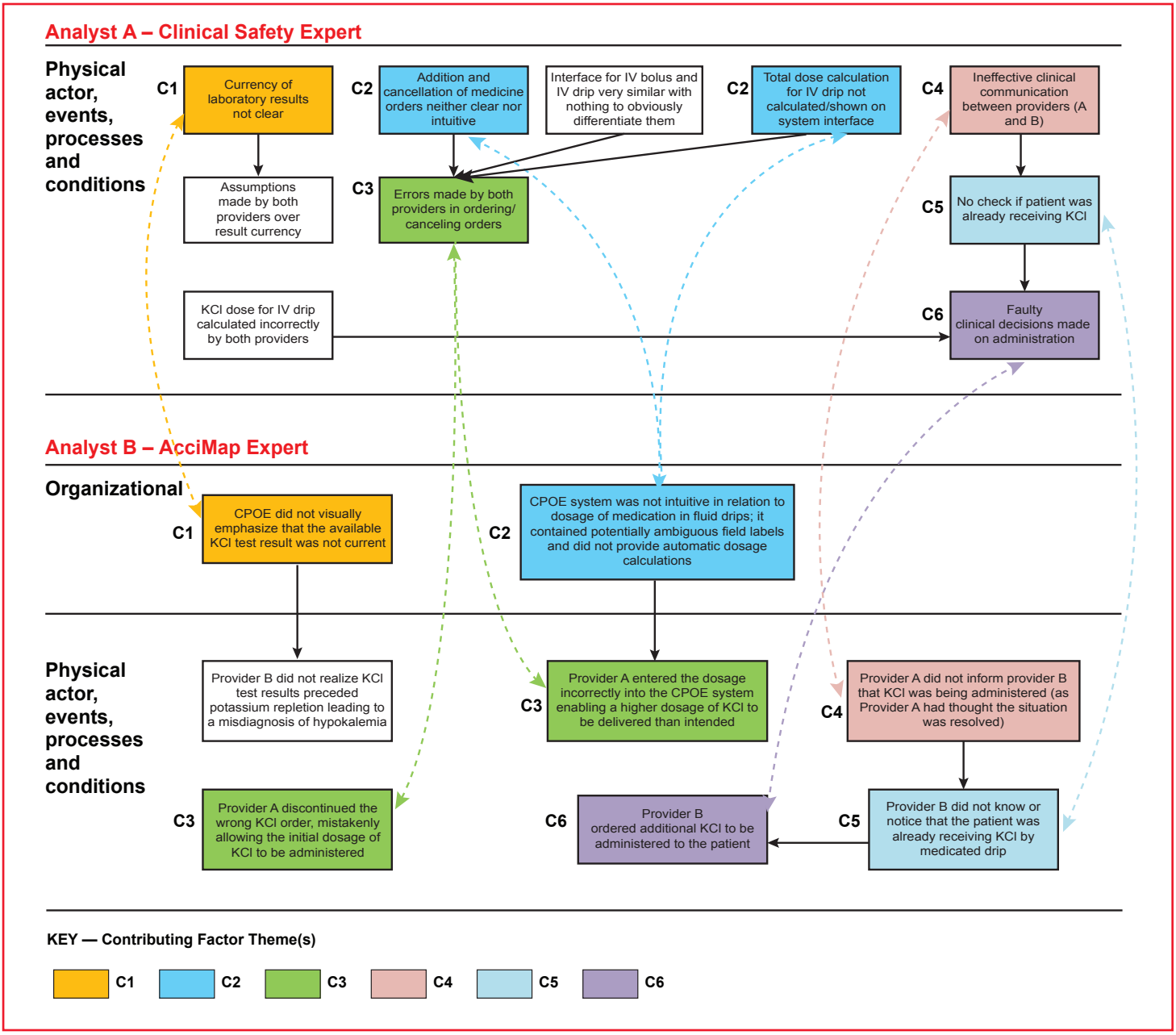

Figure 4 — Comparing the identification of similar contributing factors by both experts (A and B).

Table 1 — Contributing factor themes identified by both experts related to Providers (A and B) interacting with the CPOE system.

Code	Contributing Factor Themes
C1	The currency of the results displayed by the CPOE system and the results not being clear to the providers
C2	The CPOE system not being intuitive in terms of cancellation and addition of orders, interfaces for both IV and medicated drips looking similar, and dose calculations
C3	Errors made by providers A and B regarding ordering and cancelling orders caused the initial KCl dosage to be administered
C4	Miscommunication between providers A and B regarding the administration of KCl
C5	Provider B did not notice or check if the patient was already receiving KCl before administering an additional dose
C6	Provider B ordered additional KCl after not realizing that the results preceded the KCl depletion

Table 2 — Contrasting contributing factors identified by Analysts A and B.

	Analyst A (Clinical Safety Expert)	Analyst B (AcciMap Expert)
Physical actor events, processes, and conditions	• KCl dose for IV drip calculated incorrectly by both providers • Assumptions made by both providers regarding result currency • Excessive amounts of KCl ordered and administered	• Nursing staff not noticing and reporting duplication of orders • Provider B did not realize KCl test results preceded potassium repletion, leading to a misdiagnosis of hypokalemia
Organizational	• Organizational guidance on KCl delivery over 4 hours • *Insufficient or clinical safety testing of software product* • *Inadequate policy on clinical communications and/or ineffective training on policy*	• Inadequate human factors integration in design and testing • Inadequate training in the use of the CPOE system • Poor interface design leading to misidentification of order entries • Neither the CPOE application nor the pharmacy application was programmed to notify of excessive dosage orders or duplicate therapy • KCl IV drips are not displayed on the CPOE's medication list
External	• Poor software interface design	• None
• *Inferences*		

to themes (C1 and C2), they are considered the health organization's responsibility as noted by the AcciMap expert rather than the clinical providers' activities. The remaining similar factor themes (C4, C5, and C6) were similarly placed at the same level (physical/actor activities) by the clinical and AcciMap experts.

Causal Links within and between AcciMap Levels — In identifying causal relationships from both participants' AcciMap models, the focus is on observing whether similar links are discovered between similar contributing factors. For example, a similar causal link (Link 1) identified was between C2 (issues relating to the design of the CPOE system) and C3 (errors made in entering/cancelling wrong orders into the system) (see Figure 6). Because the two contributing factor boxes identified by Analyst A constitute a single box when similarly recognized by Analyst B (C2), the causal links are also combined to portray a singular causal link (Link 1) similar to Analyst B's causal relationship. The remaining causal links (Link 2 and Link 3) were based on contributing factor themes (C4, C5, and C6). Other causal links not similarly identified from both results indicate how participants depicted relationships between contributing factors they interpreted from the incident report. Table 3 provides the summary of the identified causal links between contributing factor themes.

Comparing Safety Recommendations — Both experts produced safety recommendations that indicated similarities and differences as shown in Table 4. For example, safety measures included those relating to the functionality and improving the CPOE system's interface. Both experts also identified the necessity of incorporating safety alerts regarding excessive and duplicate doses administered. Also, improving the interface usability of the application, including visualization and improved identification of order entries, was similarly recommended by both experts. However, while the original report included different aspects regarding improving user training of the CPOE system, the only additional recommendation not included in the report was to review staff training on using the CPOE system and, specifically *on interpreting the data correctly.*

Finally, there were differences in identifying safety measures for both the organizational and external level. Analyst A included proposed actions related to software vendors incorporating safety measures based on lessons learned to reduce clinical risks (external level). However, at the organizational level, Analyst A identified the need to review the KCl delivery concerning CPOE systems and, more interestingly, emphasized the role of a clinical safety officer. On the other hand, safety recommendations identified by the AcciMap expert (Analyst B) did not include any external countermeasures. The reason

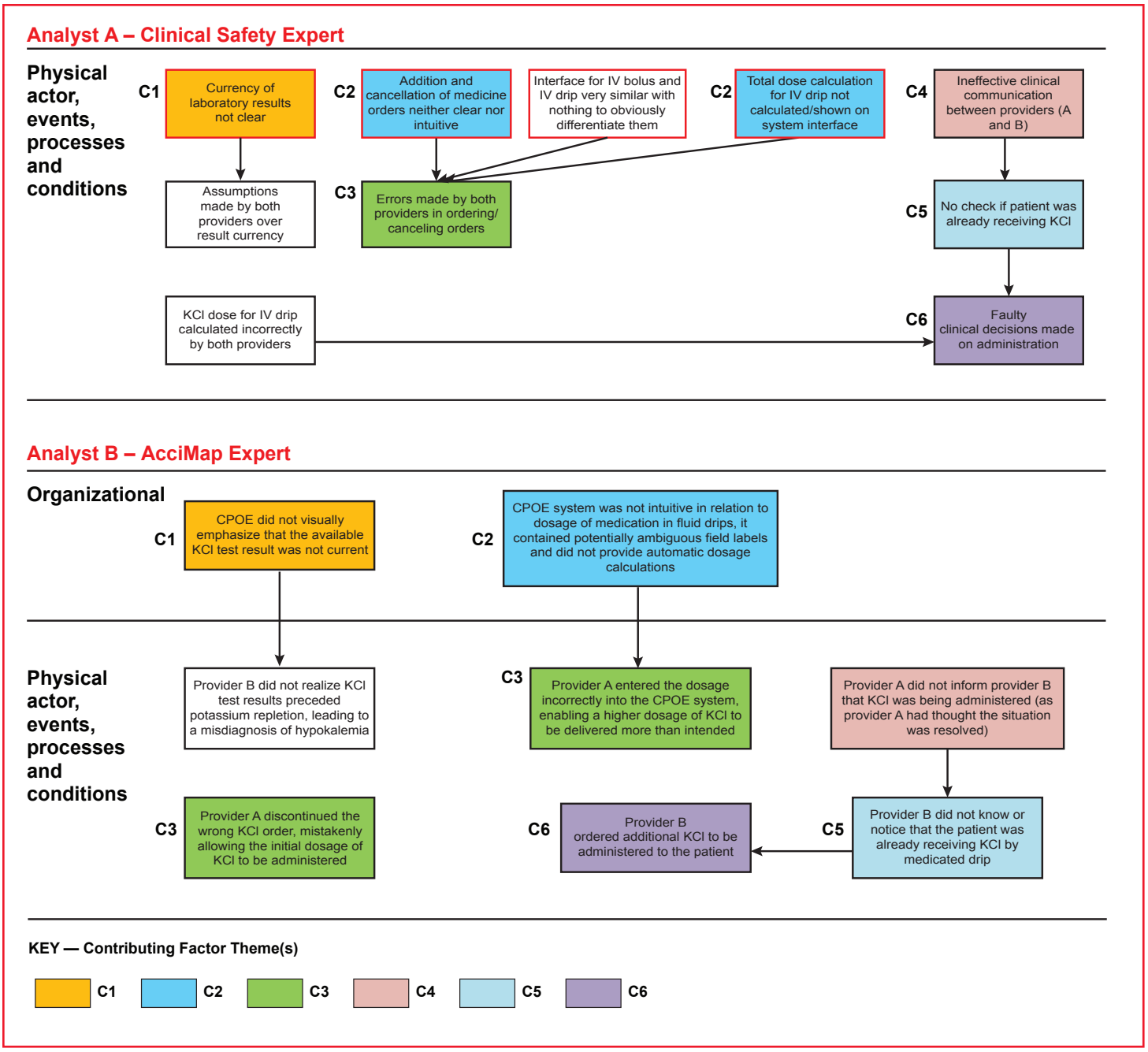

Figure 5 — Comparison of placement of contributing factors between both experts (A and B).

for not identifying safety recommendations at the external level, as emphasized by Analyst B, was that no causal relationships extended to the external level. A further reason for this was, for instance, the lack of contributing factors to explain why none of the other staff failed to identify dosage duplication, and why the CPOE system installed was presumably done without appropriate user testing and human factors input. The AcciMap expert identified additional safety recommendations that the clinical expert did not recognize. These included staff training in using the CPOE system (entering dosage information and interpreting data) and reprogramming the pharmacy application to notify of excessive dosage orders and duplicate alerts.

Interview Session with Clinical Safety Expert (Analyst A)

After the training and applying the AcciMap method to the CPOE medication error incident, a semi-structured interview with the clinical expert (Analyst A) took place. Questions were asked regarding his experience, and a summary of responses to the questions of interest are shown here:

1. Question: Did you find the AcciMap intuitive in understanding how it is applied?

The clinical expert generally found the concept and methodology of the AcciMap approach understandable. However, the participant did not regard the AcciMap method as the most intuitive approach in some respects and felt

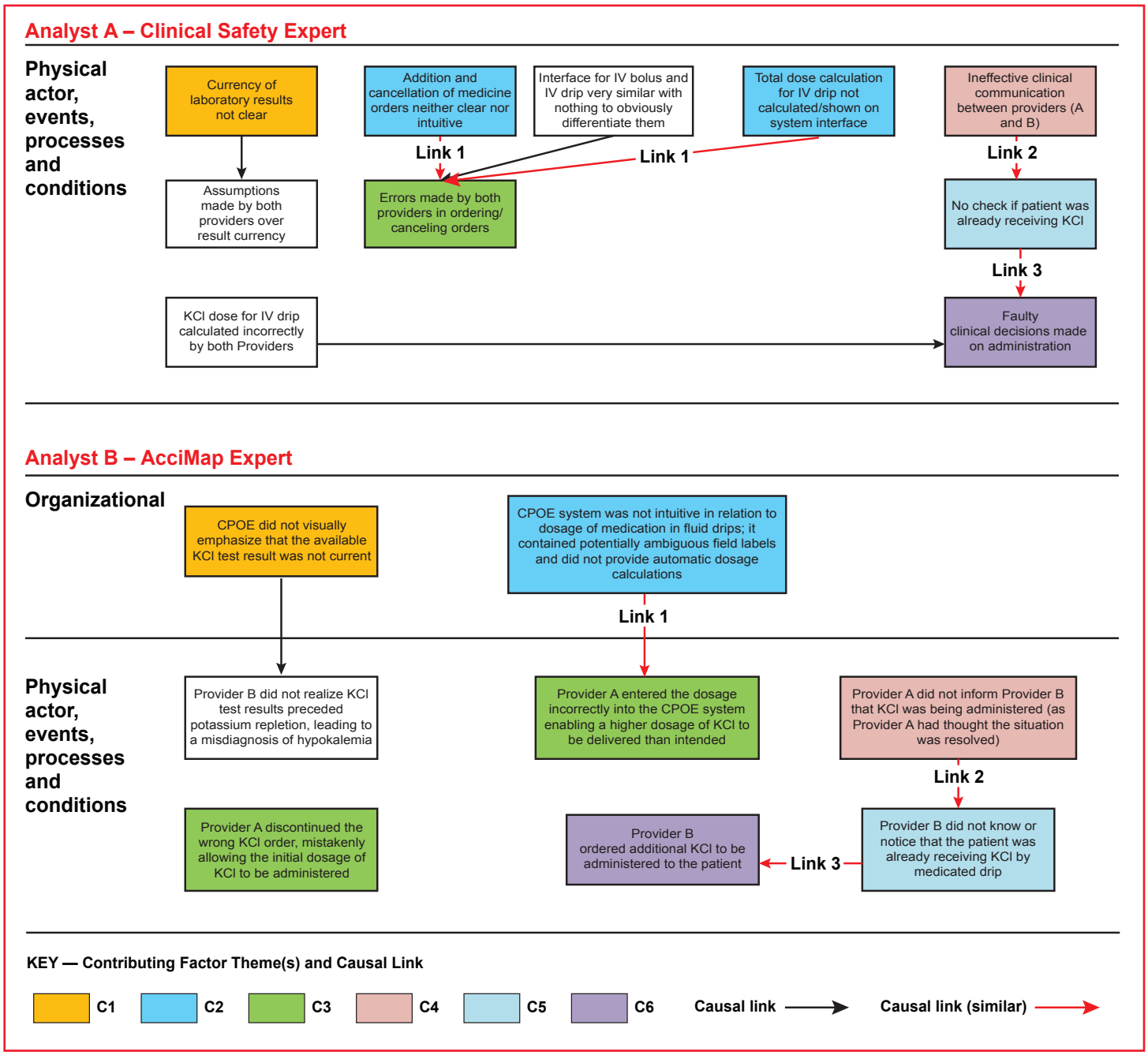

Figure 6 — Similar causal links (relationships) identified by both experts (A and B).

Table 3 — Contrasting contributing factors identified by Analysts A and B.

Code	Causal relationships
Link 1	A causal link between Contributing factors C2 and C3
Link 2	A causal link between Contributing factors C4 and C5
Link 3	A causal link between Contributing factors C5 and C6

the need for more training and experience in applying the approach effectively. For instance, the participant noted how he had to cross-reference the guideline manual regarding where to place contributing factors and how they are causally linked by determining what flows from one causal/contributing factor to another. The clinical safety expert also noted that multiple iterations were carried out, requiring referral to the guidelines to complete the analysis.

2. Question: What has been your experience based on case analysis using the AcciMap approach?

Based on the application of the method to this incident — and particularly to a previous example case used during training — the participant acknowledged that the process was reasonably painless. However, he also noted that potential missing information from incidents could create a situation where suppositions are made to ascertain

Table 4 — Safety recommendations from Analyst A and B based on the CPOE medication error incident.

Analyst A (Clinical Safety Expert)	Analyst B (AcciMap Expert)
1. External: a. Software suppliers (vendors) to review lessons learned from the incident and provide proposals for design improvements to reduce current clinical risks within the system. This should include: i. Developing clear signage within the interface to easily differentiate between IV/IM bolus and IV infusion (delivery over time) ii. Ensuring a total dose to be delivered onscreen for IV infusion calculation checks iii. Improving the visibility of the age of the most recent lab result available for the patient iv. Improving the functionality of medicine order management – ordering and cancellation processes v. Improving visualization of all current medications regardless of route of administration onto a single screen vi. Providing additional alerts where a new medicine order duplicates a current active medicine order b. Software suppliers to provide evidence of clinical safety testing and user acceptance testing, including test scripts for scenarios c. Software suppliers to provide easy access to training materials with a particular focus on the management of medication orders, including cancellations d. Software suppliers to develop feedback mechanisms from customers on functional issues/bugs/clinical safety improvements 2. Organizational: a. Review policy/guidance on KCl IV delivery with specific reference to CPOE system interface (current interface immediately and updated interface in time for an upgrade) b. Review policy/guidance on clinical communication and instigate "mandatory for all clinical staff" training on this c. Set up formal service management arrangements (ITIL standard) for system supplier engagement to ensure clinical safety and other functional issues can be fed back to the supplier d. Instigate the role of clinical safety officer concerning Health IT systems as a single point of contact for clinical safety-related IT issues	1. Comprehensive human factors review and interface design evaluation of the CPOE system to be undertaken and action taken to facilitate error reduction, detection, and recovery 2. The CPOE interface design should be reviewed and revised to ensure that: a. The currency of test results is clearly evident b. Medications provided by IV drips are included in medication lists c. Human-computer interaction design principles are followed to facilitate easy identification and interpretation of order entries d. IV dosage input options are clear, unambiguous, meet requirements (expectations) and provide automatic dosage calculations to aid error prevention. 3. The CPOE application should be programmed to notify clinicians of excessive dosage orders and duplicate therapy. 4. The pharmacy application provider should be programmed to display alerts regarding excessive dosage orders and duplicate therapy. 5. Staff training in relation to the utilization of the CPOE system should be reviewed and revised where necessary to ensure staff have the required skills, knowledge and competency to correctly enter dosage information and interpret the data provided in the CPOE system.

why certain events or decisions at the organizational level occurred in the first place. The participant regarded the method as a straightforward approach relating to its ability to graphically depict causal factors and relationships (links) compared to RCA techniques (for example, the fishbone diagram technique). However, the clinical expert also mentioned challenges that people who may not be visually oriented may face when applying the method.

3. Question: What was your experience using the AcciMap approach to identify unsafe decisions from the case study? This response was also in conjunction with identifying contributing factors, particularly at both organizational and external levels, which depends on how documented

the case report is. This view also includes whether the incident report captured relevant information regarding decisions and conditions at both levels. While this response was related to the CPOE incident analysis, the participant also referred to the previous incident used in training regarding the design and functionality of alerts [Ref. 25].

4.Question: Did you find the guidelines for applying the AcciMap approach helpful in your analysis?
The participant found the AcciMap guidelines helpful to an extent, noting how a type of language used in one environment could be different in another. However, he also highlighted the need to include professional bodies and associations as other entities at the external level. This viewpoint referred to the table of contributing factors detailed in the AcciMap guideline manual. In terms of formulating safety recommendations, the clinical expert also found the process (step 9 of Branford's training manual) straightforward and considered the AcciMap approach to be very effective in that regard.

5. Question: What are the advantages of using the standardized AcciMap approach?
The participant highlighted the advantage of using the method based on his experience using the fishbone diagram technique. He noted that while this RCA tool can group factors, it does not account for causal linkages and that linking causal/contributing factors converge to create an environment where "holes in the cheese" become apparent. This comment also indicated agreement with Svedung and Rasmussen [Ref. 22], Branford [Ref. 19], and Salmon, Cornelissen and Trotter [Ref. 21] on the benefits of applying the AcciMap approach, especially when analyzing complex adaptive socio-technical systems, including healthcare systems.

6. Question: What are the limitations of the AcciMap approach?
According to the participant, the AcciMap method is seen as "user-dependent" and opined that improving the intuitiveness of the approach and providing tighter guidance would help improve the method. The expert also indicated the time-consuming nature of the AcciMap method, noting that it is not the kind of approach that can be applied quickly or without much preparation (on the hoof) to analyze a severe incident based on the following comment: "With the fishbone technique, it's easy to be able to identify factors quickly even though it does not employ linkages. The ability of the AcciMap approach to be used for rapid deployment in a live situation will be a massive advantage and will be a key factor."

The participant also highlighted the need to consider cost versus priorities regarding the level of risk from an incident and deciding if the AcciMap method or an RCA technique is more suitable to use depending on the nature of the report and resources available [Ref. 26]. The clinical expert further mentioned that the cost of acquiring the necessary license for Microsoft applications might not be considered worth it in applying the AcciMap method. This point was regarding using the Microsoft Visio application when designing the AcciMap diagrams. However, he acknowledged that papers, sticky notes, and other free graphical programs could be used as alternatives for AcciMap analysis.

Discussion

Relating to the objectives of this study based on the analysis of the AcciMap outputs and the interview session with the clinical expert, discussions regarding if there are benefits of applying the AcciMap approach for incident analysis in healthcare are outlined in the following subsections.

Comparison and Review of AcciMap Outcomes

Comparing the AcciMap outputs from both experts as detailed in the "Comparison Between Analyst A and Analyst B" subsection, there were similarities and differences despite having the same incident data and applying the same guidelines. Also, their respective professional backgrounds must be considered, particularly because the clinical expert's background is in health informatics and has extensive knowledge regarding health IT systems, including CPOE systems. The AcciMap expert's background knowledge was in psychology and had applied accident analysis methods on railway-related incidents before this study. Despite both experts identifying similar contributing factors, there were situations where a contributing factor was presented vaguely or placed at different AcciMap levels. For example, factors recognized by the clinical expert relating to the CPOE system were placed at the physical/actor level instead of at the organizational level as set by the AcciMap expert. The reasoning for the clinical expert's decision to put them at the physical/actor level could be that both clinical providers' interaction with the software product facilitated errors in administering a high KCI dose. However, the AcciMap expert determined that factors relating to health IT systems should be within the health organization's control. The physical/actor level should detail only actions and decisions committed by clinical staff.

Another example was the clinical expert identification of a contributing factor at the external level ("Poor software interface design"). This factor will appear to be generally similar to the contributing factor theme (C3). Still, the lack of detail regarding the specific interface design issue it referred to did not allow this factor to be regarded as similar. Moreover, this factor should have been placed at the organizational level. As noted by the AcciMap expert, other differences in their respective analyses included factors relating to "CPOE and pharmacy applications not programmed to notify of excessive dosage

orders" and "inadequate training in CPOE usage." These factors were not identified in the clinical expert's AcciMap output. One contributing factor determined by the clinical expert ("organizational guidance on KCI – deliver over 4 Hrs IV") did not meet one of the guidelines regarding clarity of semantics.

Regarding causal links, only one causal link was revealed to be incorrect, according to the AcciMap expert (Analyst B). Analyst B determined that the causal direction between "providers incorrectly calculating the KCI dose" and "the total dose calculation for the IV drip not calculated on the interface" was not valid. Safety recommendations also showed some similarities, particularly in improving the interface and functionality of the CPOE system. The clinical expert provided greater detail in recommendations relating to health software providers/suppliers (external level) and review of policies regarding communication and training (organizational level). However, the clinical expert's safety measures for the external level indicate the reasoning behind the placement of the contributing factor regarding software interface design. Overall, there were significant variations, especially regarding the AcciMap level where contributing factors were placed by the clinical expert, which subsequently influenced the safety recommendations formulated. The AcciMap expert concluded that the AcciMap guidelines might not have been applied correctly in certain situations. The reason was the clinical expert's inexperience, especially regarding understanding the appropriate levels at which to place contributing factors.

Clinical Expert's Perception Based on the Interview Session

Details were drawn regarding the clinical expert's experience after applying the AcciMap method for incident analysis. The participant generally understood and appreciated the method's ability to visually analyze and identify systemic weaknesses, especially at organizational and external levels. The expert also gave a ppositive feedback regarding the AcciMap guidelines, especially when determining safety recommendations. This view was undoubtedly reflected in the safety measures derived and the clinical participant's background knowledge in health informatics and experience using IT systems like the CPOE. However, limitations were also highlighted, with one notable disadvantage being the time-consuming nature of the method. Other limitations associated with this study will be discussed in the proceeding section.

The participant (clinical safety expert) questioned its practical feasibility, mainly when applied in live investigation and analysis. This point also related to his experience using different RCA tools, including the fishbone diagram technique, which provides a relatively quick means of analyzing incidents and not does not require spending additional time and resources, particularly in a demanding and complex healthcare environment. Furthermore, the clinical expert believed that the usability aspect needs to be addressed if the AcciMap approach is to be adopted as a systemic toolkit for NHS practices. This point is considered one of the present challenges regarding why this method and other systemic accident analysis (SAA) approaches have yet to be widely applied for incident analysis in healthcare and the continued dependence on existing RCA techniques [Ref. 6].

Overall, the results from the comparative study show that despite the clinical expert's extensive health informatics and incident analysis experience, further practice in applying the AcciMap method will be needed. This process also includes using the associated guidelines correctly, especially when determining the appropriate AcciMap level for causal/contributing factors identified. In addition, focusing on the CPOE incident analysis results, the outcome would have improved if the analyst had repeated the process. However, that process will be most applicable when conducting an intra-reliability assessment, where the initial AcciMap result is compared to the final version. Furthermore, according to the clinical expert, a considerable amount of time is needed to perform a thorough analysis and apply the guidelines correctly when using the AcciMap method. For this reason, the clinical expert appeared to favor techniques implemented to analyze incidents rapidly despite acknowledging the advantages of the AcciMap approach.

Limitations of the Study

This study focused on the analysis from a clinical expert in comparison to the AcciMap expert's results. However, this study produced outcomes only from a single point of view. This constraint further reinforces Branford's argument suggesting that a team-based approach to analyzing adverse incidents may provide a more comprehensive view of the accident than from an individualistic viewpoint. Involving additional clinical participants, especially those with a computing/IT background, having experience working with health IT systems (e.g., NHS Digital), would have allowed further insights to be made from the CPOE medication error incident. In addition, this step would enable multiple users with different backgrounds to work as a team to produce a refined AcciMap output and then be compared with AcciMap experts' output

Another limitation was that while the AcciMap expert's opinion on the clinical participant's analysis was considered, the study did not capture the processes they came to arrive at their respective AcciMap models and safety recommendations. This limitation can be resolved by using audio/video recordings to capture how participants analyze and apply the AcciMap guidelines during

incident analysis. This approach would have allowed participants to explain their outcomes, decisions behind them and any challenges they encountered. However, this process was not feasible or practicable due to their work schedule and unavailability (different time zones).

Conclusion

There is a general appreciation for the AcciMap methodology and its suitability for analyzing complex socio-technical systems compared to current RCA approaches. This awareness includes its ability to graphically represent causal/contributing factors, from the external level to the physical/actor level, that are responsible for any adverse outcomes. However, results from the study and the interview showed mixed responses regarding specific aspects of its use for incident analysis — particularly for the time it takes to carry out such an analysis. While this study focused on analyzing a health IT-related incident by two different experts, results clearly showed similarities and differences regarding contributing factors, the AcciMap level at which they were placed and, ultimately, safety recommendations formulated. There is also an ongoing need for further studies to bridge the current research-practice gap regarding implementing and realizing the benefits of adopting systemic accident analysis methods in healthcare [Refs. 27 and 28]. These studies must include aspects related to this approach's utility, validity and reliability to be fully embraced in clinical practices and in conducting health IT analysis [Refs. 28, 29 and 30].

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Apendix A — Case Description: CPOE Medication Error

The patient was initially hypokalemic and was examined by the first physician (Provider A). A decision was then made to immediately replete the potassium by administering an intravenous (IV) bolus injection. As the events unfolded, the physician realized that the patient already had an IV and so administered the KCI as an additional treatment. Several events took place that resulted in the patient receiving a higher KCI dosage than what was intended. A new dosage order was written after an initial dosage order was detected to be higher than what the hospital policy allowed and so was discontinued. However, this new dosage order was entered incorrectly into the CPOE system, and it did not contain the maximum volume of the fluid to be administered [Ref. 2].

The next day, there was a changeover between the first physician and the incoming one (Provider B). The second provider was already notified to check the patient's KCI levels from the system but did not realize that the laboratory results were from before the last potassium repletion took place. As a result, the second provider thought that the KCI levels of the patient were low and so ordered an additional IV injection even when the KCI from the previous delivery had not finished running. The case was subsequently analyzed within the health organization, and safety recommendations were developed as part of their continuous learning process.

Table 5 — CPOE Medication Error Timeline.

Time	Provider	Action	Type	Description	Notes/Findings	Order No.
Saturday 13:30	A	ACT	IV Injection	40 mEq KCl IV injection over 4 hr Decision	Correct order The provider wants to change IV injection of KCl to a medicated drip to avoid pain administration	1
		DC	Drip	D5W non-medicated fluid	Discontinues an older standing order (not in table)	2
		ACT	Drip	D5W with 40 mEq KCl 1,000 mL @ 75 mL/hr	Intended for 1 L of fluid only; free text volume limit, auto-stop in 7 days	3
		DC	Drip	Preceding order discontinued	Realizes the preceding order [3] was incorrect and discontinues	4
		ACT	Drip	D5W non-medicated fluid	Enters order identical to the one just discontinued [2]	5
		ACT	Drip	D5W with 100 mEq KCl 1,000 mL @ 75 mL/hr	Second attempt to enter drip order, similar to order [3]; now with a higher dose (100 mEq)	6
		DC	IV Injection	KCl 20 mEq	Meant to discontinue order [1] but discontinued an expired order from 2 days before (not in table)	7
49-min time lag					Pharmacy calls to warn about the order [6], which has dose over the limit (100 mEq, max allowed 80 mEq)	
Saturday 14:26 (16 min)	A	DC	Drip	D5W non-medicated fluid	Discontinues non-medicated fluid order [5] in response to the call from the pharmacy	8
		DC	Drip	D5W with 100 mEq KCl 1,000 mL @ 75 mL/hr	Discontinues erroneous drip order [6] in response to the call from the pharmacy	9
		ACT	Drip	D5W with 80 mEq KCl 1,000 mL @ 75 mL/hr	Enters recommended 80 mEq. Intended for 1 L only, but no stop time entered; auto stop in 7 days	10
52-min time lag						
Saturday 15:34	A	DC	Drip	D5W with 80 mEq KCl 1,000 mL @ 75 mL/hr	The preceding order [10] discontinued	11
		ACT	Drip	D5W with 80 mEq KCl 1,000 mL @ 75 mL/hr	The same order [cf 10, 11] re-entered, runs for 36 hr and delivers 216 mEq KCl	12
27-hr time lag **Change of Providers**						
Sunday 18:36	B	ACT	IV Injection	40 mEq KCl IV injection	Misperceived older potassium laboratory values as current; did not notice running KCl drip [12]	13
34-min time lag						
Sunday 19:10	B	DC	IV Injection	40 mEq KCl IV injection	The preceding order [13] discontinued	14
		ACT	IV Injection	60 mEq KCl IV injection	Increased IV injection dose to 60 mEq	15
27-min time lag						
Sunday 19:37	B		IV Injection	40 mEq KCl IV injection	Another IV injection of KCl ordered; however, no clear evidence that it was administered	16

ACT — Activate DC — Discontinue KCl — Potassium Chloride