ICT-Enabled Time-Critical Clinical Practices: Examining the Affordances of an Information Processing Solution

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Abstract

In this paper, we present a case study of a decision-support system deployment at The Alfred Hospital, in Melbourne, Australia. This work outlines Information and Communications Technology (ICT) affordances and their actualisations in time-critical clinical practices to enable better information processing. From our study findings, we present a stage-wise model describing the role played by ICT in the context of the Trauma Centre practices. This addresses a knowledge gap surrounding the role and impact of ICT in the delivery of quality improvements to processes and culture in time-critical environments, amid increasing expenditure on ICT globally. Our model has implications for research and practice, such that we observe for the first time how information standards, synergy and renewal are developed between the system and its users in order to reduce error rates in the healthcare context. Through the study findings, we demonstrate that healthcare quality can be further refined as ICT allows for knowledge dissemination and informs existing practices.

Keywords: Time-critical clinical practice; ICT affordances; information processing

1 Introduction

Increased expenditure and the desire to improve healthcare quality are driving the adoption and research of Information and Communications Technology (ICT) in healthcare on a global scale (Braa, Monteiro & Sahay 2004; Goldschmidt 2005). The Global Health Observatory and diagnostics and laboratory technology are key programs in the World Health Organization that recognise the key role played by health statistics and ICT in contemporary healthcare practices. The Health Informatics Forum, for instance, is a network of over 28 health informatics associations and 3,500 practitioners from around the world that is generating robust discussions on the role of technology in supporting clinical practices. Whilst the implications of IT in healthcare are likely to be pervasive in the coming years, the challenge is to better understand how IT adoption in healthcare restructures the delivery system, reengineers care processes and recreates the culture in which healthcare occurs (Goldschmidt 2005).

One emergent area of research in this field is the diagnostic pathway in time-critical environments, which is a process supported through the use of clinical decision-support systems (Berner 2007). The use of decision-support systems in hospitals to enact clinical procedures and diagnostics is widespread, but there is still no consensus on how the benefits

are achieved or developed. This is important in order to better understand how decision-support technology can improve all types of healthcare decisions and transform healthcare services (Goldschmidt 2005). Given this knowledge gap, the following research question is posed in this study: How does ICT enable information processing in time-critical clinical practices? We present a case study of a decision-support system deployment at The Alfred Hospital (The Alfred), in Melbourne, Australia. In this study, we examine the application of information processing capabilities involving both computer hardware and software that deal with the storage, retrieval and use of healthcare information, data and knowledge for communication and decision making in a time-critical environment.

Our research has implications for both research and practice. We observed the impacts of ICT affordance on clinicians in time-critical clinical practices. Toward this goal, data collection was conducted to determine the actualisation of ICT affordances in order to explain user satisfaction, clinical efficacy and the impact on the preventable error rate in procedures. We find that by affording growth in the ICT knowledge base created by the end-users, the ICT is able to evolve and incorporate contemporary medical practices and procedures. Beyond the impact afforded by the introduction of the decision-support technology, we co-developed the Algorithm Designer, a component of the ICT that incorporates the clinician expertise to extend the processes supported by the system. In sum, this work outlines ICT affordances and their actualisations in time-critical clinical practices to enable better information processing.

2   Health IT and Information Processing

Health information technologies are "applications of information processing" involving both hardware and software that deal with the storage, retrieval, sharing and use of healthcare information, data and knowledge for communication and decision making (Goldschmidt 2005, p. 71). They can include applications ranging from electronic health record, personal health record, decision-support and telemedicine systems. This notion of information processing posits that such organisations and individuals need quality information and the capability to gather, interpret, synthesise and disseminate information properly in order to cope with uncertainties (e.g. in technology, demand and supply) and improve decision making (Tushman & Nadler 1978). Information processing constitutes needs, capabilities and the fit between the two in order to obtain desired outcomes (Premkumar, Ramamurthy & Saunders 2005).

The literature around information processing focuses on: (1) developing buffers to reduce the effect of uncertainty, and (2) implementing structural mechanisms and information processing capabilities to enhance the information flow and thereby reduce uncertainty. According to the literature, an information processing network and an organisation's control mechanisms are central to developing these information processing capabilities. The structure of an information processing network describes the patterns through which communication is expedited and information is processed (Ahuja & Carley 1999). Information processing networks are dynamic network-based information processing structures which operate as a coordination mechanism (Kwon, Oh & Jeon 2007). Over time, continual exposure to a specific type of organisational structure will propel individuals toward proficiency in processing information and will bolster their ability and confidence to solve problems, through ongoing learning, in a manner consistent with this structure (Turner & Makhija 2012). In other words, structures direct or adapt the behaviour of individuals by facilitating the individuals' ability to obtain and derive meaning from the key information related to their work. This view of the individual interacting with the system to achieve information processing capabilities is reflected in the theoretical construct described below.

3   ICT Affordances

In this study, ICT affordances refer to action potential, that is, to what individuals or organisations with particular purposes can do with technology or information systems (Majchrzak & Markus 2012; Strong, Volkoff, Johnson, Pelletier, Tulu, Bar-On, Trudel & Garber 2014). Various scholars have advocated the use of the theory of affordance to inform the study

of IT-associated organisational change processes (Volkoff & Strong 2013), to theorise how technologies offer action possibilities to work teams and organisational units (Gaver 1991; Robey, Anderson & Raymond 2013) and to create new organisational forms (Leonardi 2011; Zammuto, Griffith, Majchrzak, Dougherty & Faraj 2007). The theory of affordance arose primarily from the field of ecological psychology (Gibson 1977). It explains how the inherent values and meanings of things in the environment are perceived, and how this information can be used to define the possibilities and limits for action that a material object offers to an actor or how a material becomes implicated in human activity. A number of formalisations of the concept of affordance have been advanced, most notably as dispositional properties of the environment (Turvey 1992), relations between the abilities of organisms and features of the environment (Chemero 2003), and opportunities for action (Stoffregen 2003).

The focused nature of the affordance concept is useful to examine the effects of introducing technology to organisations, such that it allows us to explain organisational-level affordances in a manner consistent with critical realism (Volkoff et al. 2013). Health IT, ranging from electronic health record systems to decision-support systems and telemedicine systems, affords clinicians the potential to access patient data and medical history electronically and independently of their institution or location. This allows patient records to be entered into decision-support systems to inform pertinent healthcare decisions through the retrieval and use of healthcare information, data and knowledge. A key benefit of ICT adoption in healthcare recordkeeping is the affordance of information dissemination across medical facilities (Chad 2011; Goldschmidt 2005).

On the other hand, scholars have flagged a number of considerations to be taken into account when applying the affordance lens. According to Volkoff et al. (2013), affordances are a type or subset of generative mechanisms. Just as generative mechanisms are non-deterministic, different actors may *actualise* affordances differently. Just as a mechanism exists whether or not it is exercised, some affordances may never be actualised (or even perceived) in a real-world domain unless there exists someone who—in addition to having the necessary capability—has an intention to actualise the affordance or is motivated by *goals* that are served by actualising the affordance. In IS, efficacy focuses on individuals' capabilities to competently use computers (computer self-efficacy) in measurements of computer use (Compeau & Higgins 1995). Efficacy in general refers to the level of control wielded by an individual (e.g. the role of an expert) or by a community. Collective efficacy is high in cohesive communities with mutual trust and is low in communities that are not cohesive and that do not have mutual trust.

In addition, it is noteworthy that in a real-world domain, multiple affordances are present at the same time such that IT-associated organisational change can be viewed as interacting strands of affordances spanning time. Therefore, in addition to uncovering these affordances, researchers must pay attention to the nature of the relationships between affordances in order to examine the different structural levels from which they emerge from their constituent parts (Volkoff et al. 2013). Hence, researchers must account for the way in which affordances – when actualised – unfold temporally.

4   Case Study: Trauma Centre, The Alfred Hospital

For this study, we use a case study method to exemplify how the application of ICT-enabled information processing solutions aids decision making in time-critical clinical practices. The case study research methodology is particularly appropriate for this study for a number of reasons. First, case study research addresses 'how' research questions (Walsham 1995) whilst examining processes (Gephart 2004), and our research question delves into the role of ICT affordances in enabling time-critical clinical practices. Second, because we established that time-critical clinical practices form an inherently complex and multi-dimensional phenomenon, an objective approach to research is difficult (Koch & Schultze 2011), making it more appropriate to examine the phenomenon by interpreting the shared understanding of the relevant stakeholders (Klein & Myers 1999) who, in this case, are clinicians.

Hence, we selected and examined the Trauma Centre at The Alfred—a site of a major computerised approach to trauma management—as our case study. The case selection was based on the following criteria: (1) the case must be a widely recognised time-critical clinical practice in order to fulfil our examination of activities, (2) the processes of the clinical practice must be reasonably complex in order for the underlying mechanisms to be studied, which means that information processing networks and activities exist, and (3) the case study must present opportunities for the ethnographic research of clinicians, in order to study the efficacy of the actors responsible for clinical practices.

We narrowed the focus of our inquiry and data analysis to three pertinent themes: (1) the structure and environment of the Trauma Centre, (2) the actions of the clinicians and the actions of the Centre's technology partners, and (3) the development of time-critical information processing capabilities achieved through healthcare ICT affordances. To this end, the authors conducted site visits to The Alfred. We conducted semi-structured interviews (Taylor & Bogdan 1998) with doctors, nurses and other clinicians, and software developers, and collected secondary data from various documents related to the project. We also drew on secondary data such as newspaper articles and the hospital's media releases to triangulate our mappings. In addition, three of the authors of this paper were actively involved in the design and implementation phases of the Trauma Centre's decision-support system project, specifically in the algorithm design component (discussed in detail in Section 5.1). Table 1 lists the breakdown of the participants by role and experience.

Participant(s) Role	# of participants	Years of experience				Questions, topics discussed
		< 1	1-5	6-10	> 10	
Airway Nurse	7	4	1	2	-	Airway procedures, pre- and post-procedure checklists in TRR
Anaesthetist/ Registrar	6		2	1	3	Anaesthetist duties and procedures, patient recovery checklist in TRR
Circulation Scout Nurse	7	2	2	2	1	Circulation procedures, pre- and post-procedure checklists
Emergency Physician/Registrar	4	1	3			Range of responsibilities in TRR
Radiographer	6	1	3		2	Frequency of scans, pre- and post-scan process
Trauma Nurse Leader	6	1	2	1	2	TRR data entry and communication processes
Trauma Medical Team Leader	3	-	1	1	1	Team and expertise sizes, team communication, system use
Trauma Orderly	2	-	1		1	Role and responsibilities in TRR process
Trauma Surgeon/Registrar	7	1	2	4	-	Role and responsibilities in TRR process

Table 1: Participant demographics

Forty-eight professionals participated in this study, some of whom opted to not share their demographic information. The participants were volunteers from among The Alfred's trauma staff who had been rostered into trauma teams. The size of the trauma team for each operating scenario ranged from six to twenty people, based on the expertise required to treat the trauma. As multiple scenarios were run with trauma teams of differing sizes, deliberate effort was made in our participant grouping to ensure that each participant would only participate in, at most, two different scenarios. Generally, all the participants were queried about medical treatments, patient reception procedures, treatment protocol, typical responsibilities, patient arrival

information, and post-trauma recovery. Questions specific to the participants' roles are also listed in Table 1.

5   Trauma Reception and Resuscitation at the Alfred

The Trauma Centre at The Alfred is the site of a major investigation into the impact of a computerised and algorithmic approach to trauma management, through the Trauma Reception and Resuscitation (TRR) project.[1] The objective of this project is to assist trauma teams by guiding diagnoses with precedents and to facilitate the review processes of the procedures that are performed for compliance. Previous studies in Australia, Europe and the United States demonstrate that the methodical approaches drawn from other high-risk domains should be incorporated into healthcare practices in order to reduce preventable errors and minimise patient harm and risk (The Joint Commission 2009); however, there is some ambiguity in the results associated with measuring compliance with algorithms in real time. Therefore, a major aim of the TRR project is to establish a standardised environment. Meeting this aim involves testing whether compliance with evidence-based medical approaches will indeed improve outcomes in major trauma management with a measurable reduction in errors.

5.1   The ICT Artefact: The Trauma Reception and Resuscitation System

At the heart of the TRR project is the TRR system that guides medical staff during the crucial first 30 minutes of trauma reception and resuscitation, as this time period has been observed to have a significant impact on preventable morbidity and mortality. Patient data including vital signs, confirmed and/or unconfirmed diagnoses and treatments are entered into the TRR system directly via a touchscreen monitor by the Trauma Nurse Leader (TNL). Based on these data, computerised algorithms prompt the trauma team in real time to confirm the state of the patient, perform procedures and administer drugs as well as assist in diagnosing injuries. The TRR system displays prompts and patient data for the trauma team on a large overhead 40" monitor mounted on the wall of the trauma bay. Compliance with the algorithms is guided by real-time computer-generated prompts linked to real-time data collection. A computerised video audit is used to verify compliance and to assess error rates.

The medical algorithms at the core of the TRR system serve to guide and support the trauma team. The algorithms are not prescriptive, nor do they replace the expertise of the medical staff. The algorithms have been, and will continue to be, subject to close scrutiny, discussion and evaluation by trauma specialists. Figure 1 illustrates the setting of the TRR system, including the monitor and the interface. Successfully integrating a computer system into the specialised and highly pressured trauma care environment required close collaboration between the software developers (see footnote 1) and the medical staff at The Alfred. The other key stakeholders in the TRR project consist of over 10 domestic and international hospitals, research institutes and trauma centres. The names of the stakeholders and collaborating organisations are removed due to the review process. These details are available from the authors on request.

We focused on the relationships and interactions between the subject matter experts (SMEs) at The Alfred, namely, the clinicians at the Trauma Centre, and the software developers in using the TRR system and developing user-centred algorithms. The result of this interaction included the development of an innovative feature of the system, called the Algorithm Designer, which enables the medical staff themselves to create medical algorithms in an electronic form that is compatible with the system. The enrichment process supported by the Algorithm Designer allows a trauma team to commune outside of a time-critical environment to develop therapeutic and diagnostic courses of action based on patient conditions. The benefits of the Algorithm Designer include: 1) the removal of time pressure, 2) the absence of

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[1] The TRR project is a joint effort of The Alfred Hospital and the Swinburne Software Innovation Lab. For details, visit: http://trrproject.com/

significant training required for the SMEs to enrich the system knowledge base, 3) the affordance of a self-sustaining knowledge base available for professionals to employ for review and training purposes, and 4) the medical staff have control over the reference data upon which the medical algorithms depend.

Preparation → Treatment and Diagnostics → Maintenance

Figure 1: Setting of the Trauma Reception and Resuscitation system[2]

6   ICT Affordances in Trauma Reception and Resuscitation

This section presents the preliminary findings from the data analysis of the interview notes and documents gathered during the data collection. The discussion focuses on the three crucial phases in integrating the TRR system into trauma reception and resuscitation process. For each phase, we discuss the themes, sub-themes and constructs, and representative evidence from our study that pertains to the ICT affordances, its actualization and finally impact on the reference process. Reiterating our analytical lens, affordances here refer to the potential function of the software and facilities in enabling the clinicians.

6.1   Preparation Phase

The first thirty minutes of trauma reception and resuscitation have a significant impact on patient outcomes due to the often serious condition in which the patients arrive at the hospital (Kramer 2009). It falls to the prerogative of the trauma team to assess and determine the therapeutic and diagnostic pathways based on the individual patient's condition. We identify this as the preparation phase and discuss the potential IT affordances and impacts on the medical staff at The Alfred and the developers when creating algorithms for the TRR system.

Correctly recognising afflictions and injuries and dealing with them is critical, as errors invite preventable morbidity and mortality. A 28 member multi-disciplinary medical team comprising nurses, emergency physicians, anaesthetists and trauma surgeons served as SMEs in the development of the algorithms for the preparation phase. The SMEs were convened to acquire, collate and curate the most recently available and relevant evidence related to trauma management. The SMEs took nine months to construct the algorithms, which are placed in the category of Early Management of Severe Trauma (Civil 1999). The SME team was provided with several standard guidelines for translating their recommendations into medical algorithms and their contingencies. For instance, the SME teams were provided with instructions to: i) identify key 'decision points' that require a response from the trauma team, ii) limit the options, and iii) define a reasonable time for task performance.

The process of converting medical procedures into computer-based algorithms created lively discussions among the medical staff. Fortunately, some of the medical staff understood the constraints of binary logic and were able to assist in identifying the criteria needed for algorithm development. Trauma specialists added a timeline to the best-practice algorithms to

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[2] Images taken with permission of the TRR project.

enable computerisation and real-time prompts. Informal rapid prototyping involving close collaboration between developers and clinicians was a successful methodology for developing the Algorithm Designer and its testing tool, called the Algorithm Tester. Table 2 summarises the IT affordances and impacts in the preparation phase.

Theme	Construct	Representative Evidence
IT affordances in preparation	Standardised information	*"Team members do not arrive at the same time, whenever a new member arrives, one of us will have to stop and bring the new arrival up to date with the patient and the treatments performed thus far."* – Circulation Scout Nurse
	Process contingencies	*"Our systems [processes] are contingencies, called upon when needed, normally suggested by a nurse if they aren't busy doing another procedure."* – Trauma Medical Team Leader
Actualisation and IT processing capabilities	Develop informed efficacy	*"When I walk into the bay and look up, I can see the status of the patient as well as procedures performed thus far, bringing me up to speed."* – Radiographer
	Develop process compliance	*"It is always the small things, like a tetanus booster shot post intubation that gets missed. The symptoms arising from this misstep only appear during recovery leading to extended stay for the patient and an investigative process for us to identify possible causes."* – Emergency Physician
Impact on preparation	Accurate diagnosis and scanning of patient needs	*"The FAST [Focused assessment with sonography for trauma] test, which scans the abdomen for internal bleeding, only takes 30 seconds to perform, but if there are major external injuries, it gets missed amongst the chaos."* – Emergency Registrar

Table 2. IT affordances and impacts in the preparation phase

The TRR algorithms represent an advance in medical algorithm design because a suggested time frame is allocated to each algorithm step. This enables the generation of real-time prompts to guide effective trauma management. It also provides an evidence-based guide for the time of intervention and duration of procedure. The algorithms cover the majority of presentations to the Trauma Centre, and improving compliance. The majority of evidence used to inform the algorithms was based on clinical opinion or consensus because the SME team found that well-established evidence to support trauma management was scarce. The algorithms prompt trauma staff to perform accurate actions based on the patient's vital signs and guide staff on the procedures to be performed, drugs to be administered and the diagnosis of injuries, and are accompanied by written evidence published in a trauma manual.

6.2 Diagnosis and Treatment Phase

When the TRR system is operating, it compares the externally inputted data with the reference data in order to generate the outputs, which include visual prompts suggesting diagnoses and treatments. We identify this as the diagnosis and treatment phase and summarise the IT affordances and impacts of implementing and using the TRR systems.

Some algorithms are triggered immediately after the patient arrives in the trauma bay. Other algorithms are triggered by the input of patient data captured directly from the vital signs monitor or via manual input, and others are triggered by particular diagnoses, treatments, vital signs or particular combinations of these. Since the number of prompts on the screen at any one time is restricted to four, each prompt is allocated a level of urgency to ensure that medical staff are prompted to perform current and critical procedures before non-critical procedures. To successfully link the medical algorithms created by the clinicians with the TRR system, it was essential to enforce a standard format. These algorithms, although created individually, are combined into a single file before being uploaded into the TRR system. The TRR system

provides hospital trauma teams with access to computerised decision support for the first 30 minutes of trauma management. The system depends on evidence-based medical algorithms that are prepared as explained earlier.

Theme	Construct	Representative Evidence
IT affordances in diagnosis	Real-time access to known (patient) records	*"Why don't we just make available what we wanted to measure real time? It wouldn't be very helpful if it only raised the issue after the fact."* – Airway Nurse
	Information currency in situation	*"We now know chest drains take eleven minutes, from making the decision to getting someone to scrub up and put in the chest drain. Now, with chest injuries, we will have someone already sterile, reducing the procedure time by seven minutes."* – Trauma Orderly
Actualisation and IT processing capabilities	Enabled continuous information stream	*"We now have a universal measurement tool that records and tracks the trauma, something we didn't have before. The information recorded, with context, is so rich, especially when looked at during our weekly audits."* – Trauma Surgeon
	Ensure compliant monitoring	*"Now that we have time-stamping for our treatments as they happen, we can trace causality within the context of patient vitals during the fact, supported by video evidence."* – Anaesthetist
Impact on diagnosis	Revised checklist of procedures and protocols	*"I wanted to implement a checklist for pre-intubation that had to be vocalised and followed so as to minimise loss of the airway. I had no way of objectively coming up with it till I had access to pre- and post-checklist trauma transcripts to review if having such a checklist would be fruitful."* – Emergency Physician *"Our blood transfusion rates have almost halved, because we were now paying attention to all these other things that might have caused the blood loss to begin with. However, this data in isolation was considered an error, as people were not getting any blood, so we had to revise our protocols to account for what we now call accepted variations."* – Emergency Registrar

Table 3. IT affordances and impacts in the diagnosis and treatment phase

The TRR system in the trauma bay is set up with two screens. A large overhead screen enables the trauma team to view the patient data and action prompts continuously. A touchscreen is managed by the TNL who is responsible for monitoring the automated data entry and for entering the manual data. Preparation prompts appear on both the touchscreen and the overhead screen to enable team members to carry out the necessary action(s) while communicating with the TNL who enters the data into the system. 'Vital signs check' prompts only appear on the touchscreen because the data are usually captured from the vital signs monitor and are readily accessible to the TNL who is in a position to confirm the accuracy. Table 3 presents a summary of the IT affordances and impacts in the diagnosis and treatment phase.

6.3 System Maintenance Phase

In practice, all the medical algorithms are subject to an ongoing process of evaluation and amendment. All parties in the project came to realise that a custom-built tool was needed to enable the medical staff to continue to create and maintain the algorithms themselves whenever new evidence becomes available and when protocols or practices change. We identify this as the system maintenance phase, and we outline the IT affordances and impacts of implementing and using auxiliary systems observed.

Several months into the design process, a design tool was added to the clinician's software requirements. An alternative to providing the clinicians with a design tool was for the developers to code all the algorithms themselves. This option was rejected for both the period of system development and the period of system maintenance following deployment as being

neither time-efficient for the developers nor cost-effective for the clinicians. The software developers had a constrained timeline for development and they realised that converting the medical algorithms, already created in Visio, into a format compatible with their custom-built software would take a considerable amount of their development time. Initially, the medical staff provided about a dozen algorithms; however, this number was expected to increase over time. Some of the algorithms had a relatively simple logic structure, but others were complex and required medical knowledge to fully appreciate the structure.

Theme	Construct	Representative Evidence
IT affordances in maintenance	An objective system, (eliminating subjectivity)	*"Time to interventions was also difficult to record, it was challenging to stop and note all this information. Additionally, having to record aseptic techniques, complications was difficult as I would be busy treating the complication."* – Trauma Medical Team Leader *"It's easy to record a surgery and have two professors watch it and go- oh should have done this, should have done that, etc. But how can we take the subjectivity out of it? How can we standardise what was expected so that we can check for compliance?"* – Anaesthetist
	Communal and committed users	*"People now have to commit, if someone is listening to the chest to hear if the tube is in the right place, they have to commit and vocalise – air entry equal? There is no remaining silent. Is there a fractured femur? Maybe? Okay, we now have an unconfirmed fractured femur on the record."* – Trauma Nurse Leader
Actualisation and IT-enabled processing capabilities	Build continuous sustainable knowledge base	*"We review everything weekly to assess and identify areas of improvement, in terms of patient morbidity and mortality, massive transfusions (of blood), major complications, to identify why these events happen, and if they were preventable. We had to rely on paper documentation made during the time-critical treatment, which may have missing notes."* – Emergency Registrar
	Build inclusiveness	*"Now that we have time-stamping for our treatments as they happen, we can trace causality within the context of patient vitals during the fact, supported by video evidence."* – Radiographer
Impact on maintenance	Team proficiency	*"On a voluntary basis, junior consultants have the option to use the TRR to track them, provided the results are confidential, so that they may self assess for performance appraisals. Furthermore, they can review their transcript with a more experienced team member to identify areas of improvement."* – Trauma Medical Team Leader *"Teamwork has improved; everyone is on the same page, all the time."* – Circulation Scout Nurse

Table 4. IT affordances and impacts in the system maintenance phase

The Algorithm Designer became a versatile tool that enables the clinicians to modify and update the TRR system after deployment. Eventually, the tool was developed simultaneously with, but separately from, the main TRR system. A rapid prototyping technique was used to build and successively modify the Algorithm Designer during a close, informal collaboration between the developers and the trauma specialists. The Algorithm Designer and Algorithm Tester provide intuitive, easy-to-use interfaces enabling trained medical staff to translate the medical algorithms into an electronic format that is compatible with the TRR system. The tools enable the committed clinicians to both design and test the medical algorithms. The Algorithm Designer serves two purposes: it allows the user to create and edit all the medical reference data used by the system and, as the name suggests, it allows the user to design medical algorithms. The reference data consist of all treatments, diagnoses, injury mechanisms and other communal data used by the TRR system, developing into a knowledge base. The

algorithms rely on the reference data to describe the various medical procedures which may need to be performed on a trauma patient. The application also performs numerous automated checks and displays appropriate warning and information dialogs as the user adds and removes symbols from the algorithm. Table 4 presents a summary of the IT affordances and impacts in the system maintenance phase.

In view of the critical importance of algorithm accuracy to patient safety, it is essential that each algorithm be thoroughly tested before it is integrated into the TRR system. The Algorithm Tester incorporates the same algorithm processing engine component used by the TRR system to process algorithms and generate prompts. The Algorithm Tester is designed to test the operation of the algorithms by accepting inputs (e.g. treatments, diagnoses and vital signs), process the logical flow of the algorithm nodes, and output appropriate prompts for action by the user. The Algorithm Tester simulates the operation of the algorithm as it would be in the live system and allows the designer to check the accuracy of all the prompts that will be generated in the live system. It enables the user to input test data and to confirm that the required action prompts appear at the specified times and with the specified urgency rating (high, medium or low). Once tested and considered to be satisfactory from the medical perspective, the algorithms are saved and uploaded by the clinician into the TRR system.

7   Discussion and Contribution

Our study findings demonstrate the impact of ICT affordances on clinicians in a time-critical clinical practice through a case study of the deployment of a decision-support system at The Alfred Hospital in Melbourne, Australia. From our study findings, we derive and present a summary stage-wise model of how clinical ICT affordances are offered.
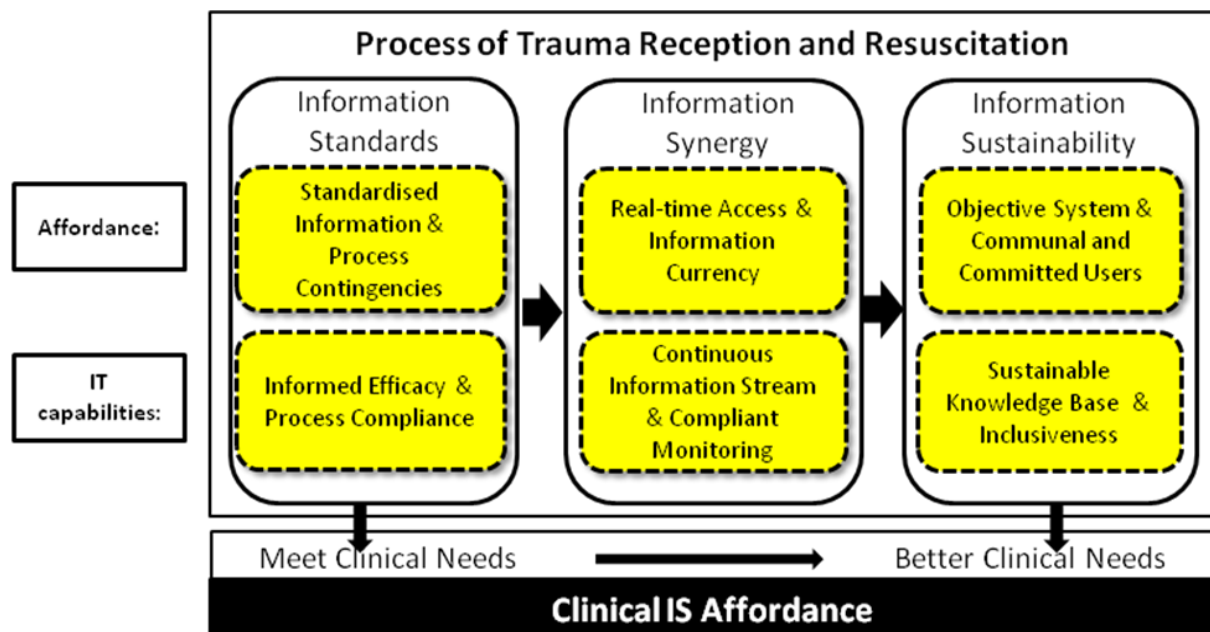

Figure 2: Summary stage-wise model of how clinical ICT affordance are offered in the trauma reception and resuscitation process

The TRR system is designed to provide trauma teams with access to real-time best practice in trauma management by providing decision-support software for the first 30 minutes of trauma management. One of the major factors contributing to the successful acceptance of the system was the provision of a facility for clinicians to create and maintain the medical algorithms on which the system is based. The Algorithm Designer is an auxiliary software tool that enables the trauma specialists to adapt the system to meet their own particular needs. Using it, clinicians can add, upgrade and delete the algorithms and the reference data upon which the algorithms are based. Close collaboration between the developers and the clinicians combined

with the rapid prototyping methodology for development of the software were critical factors in the system's successful implementation. Although initially there were minor problems as a result of giving the clinicians control over the maintenance of the medical algorithms, the benefits are overwhelming because the medical aspects of the deployed system are under the ongoing control of the trauma specialists. Figure 2 illustrates how clinical IT affordances are offered in the process of trauma reception and resuscitation in the stage-wise model. The remainder of this section discusses the development of information standards, information synergy and information sustainability in the TRR system.

7.1 Development of Information Standards

The first step towards creating a standardised environment for trauma management is to develop computerised medical algorithms. In order to do so, the information in the system must conform to a well-understood syntax and vernacular with which the trauma teams are familiar. The main objective of these algorithms is to identify and document standards for clinical trauma management derived from empirical evidence and best-practice trauma management approaches. In addition, the algorithms afford error detection and measurement, where error is defined as deviation from the algorithms as applied in a standard physical environment.

We observed that the errors of omission were reduced by "at least 20%" [Trauma Medical Team Leader] due to the establishment of standardised best practices. An error of omission describes non-compliance with a process when administering a treatment that would lead to consequences of low severity if the error occurs in isolation. For instance, when intubating a patient, a tetanus booster shot should be administered. Should the tetanus shot not be administered, it would be considered an error of omission. The consequences of not administering the shot could potentially lead to a longer recovery process for the patient, which directly translates to higher overheads of care and resource expenditure. By comprehensively tracking all procedures and treatments, prompts can be issued to avoid such errors. By reducing the cognitive overhead of stopping to brief any team member who arrives in the trauma bay to update them on the patient status and sequence of treatment thus far, the trauma team is afforded better focus on the task at hand. The display readout of the patient status and treatment administered is also consistent, which means that all members of the team, whether the newly arrived team members or the initial responders, are aware of the same precise information. The precision of data input also leads to concise and committed recordkeeping. As patients undergo treatment, each team member brings their skills to the fore to diagnose and address the injuries they see. Additionally, as they treat the immediately apparent injuries, postulations on causal or coupled injuries (e.g. "It might be a broken rib cage causing this" or "This may have caused some abdominal bleeding, can someone check?") can be vocalised and verified systematically, without being forgotten. Verifying and committing to follow-through with such actions results in less activation of contingency processes as a result of mistakes and omissions.

The Algorithm Designer is not only innovative for the purpose for which it is designed, it also opens up possibilities for use in other medical settings. Using the Algorithm Designer, medical staff in a different environment can amend or replace the algorithms to meet their particular situations. For example, the algorithms designed by the trauma specialists at The Alfred deal with approximately 90% of all trauma cases treated at that hospital. Victims of gunshot wounds are rare. Hospitals in other parts of the world that encounter such wounds with higher frequency would be able to develop new algorithms to deal with these cases.

The Algorithm Designer has the necessary flexibility to be adapted to any situation. The software also has great potential for use as a training tool for inexperienced trauma staff. In addition, standardisation serves to bridge the gaps in information localisation and globalisation, most notably in conversions between imperial and metric systems when administering drugs. Another opportunity for standards is between vernaculars used in different countries, e.g. such as "O2 Sat" (in Australia) vs "Oxygen Saturation" (in the US); this would reduce the delay from seeking clarification or reduce the margin of error from

misunderstandings. Through the data entry mechanisms in the Algorithm Designer, such discrepancies can be avoided by enforcing data input formats, whereas the data output could still be displayed with localisation to the relevant region. This translates to a system module that guides user input so as to achieve standardised output that is understandable to all the job roles in the trauma room. The by-product of this also ensures that if a well-established course of action is the standard response to specific patient conditions, the team can respond by applying their training immediately.

7.2 Development of Information Synergy

Informal rapid prototyping involving close collaboration between developers and clinicians was a successful methodology for developing the Algorithm Designer and the Algorithm Tester. The trauma specialists added a timeline to best-practice algorithms, which enabled computerisation and real-time prompts.

The Algorithm Designer and the TRR system were not networked. The software developers were well aware of this issue. Although some problems arose when the main TRR system was not being developed concurrently with the Algorithm Designer, the onus was on the user to ensure consistency between versions of the TRR system and the Algorithm Designer. To overcome the potential problem of uploading mismatched algorithms and reference data into the TRR system, the same automated checks that were used by the Algorithm Designer to test the algorithms were performed whenever the TRR system was started, warning the user appropriately if mismatched algorithm and reference data conditions were detected.

Data from sources such as monitoring equipment, patient records and medical practices need to be processed, consolidated and reported by the TRR system. This relies on the natural synergy and pre- and post-conditions of patient vitals and history in order to determine appropriate procedures and courses of action. As the algorithms are aggregated from precedent, the algorithms displayed in the trauma bay give all the members of the team access to experience in treating wounds and injuries in real time. This is in contrast to relying only on the recollection of the more experienced members in the team and the leadership in the bay. Patient history is incorporated in the algorithms if available, and conditions can be verified by the TRR prior to advocating a diagnostic pathway.

Furthermore, subjectivity is removed from the treatment of patients by the clinicians' observation of the standardised data and their use of it to decompose processes into modular treatments. In the Trauma Centre, this led to new findings during audits of instances of the trauma team's performance that, without the contextual information such as time-stamping, video recordings and transcripts of procedures, would have been considered poor treatment. For instance, an interviewee was noted to mention:

> *"A new team member would come in and say, 'oh, patient was in shock, blood pressure was 90'. Whereas now, the record reflects the patient blood pressure was normal for the past 15 minutes, but morphine was just administered, lowering the blood pressure just before the team member arrived; this information is critical in informing his next action."*

Additional findings were that blood transfusions were halved. Typically, the audit team would have considered this statistic to indicate that the patients were not given enough blood. However, with the contextual information, it was observed that the TRR system was enforcing due diligence and compliance by reminding physicians to follow through with their treatments; hence, patients needed fewer blood transfusions. This also led to the discovery and proposal of acceptable variations in compliance for The Alfred.

This information synergy, however, relies on having information standards in order to afford opportunities to use the algorithms developed by other hospitals. The compliance introduced by information standards and synergy effectively allows the trauma clinicians to incorporate the collective and empirical experience of trauma clinicians and use it when assessing patient conditions to determine diagnostic pathways – a step that was not possible prior to the IT adoption.

7.3   Development of Information Sustainability

Auxiliary systems afford clinicians the ability to add, upgrade and delete the algorithms and the reference data upon which the algorithms are based. We describe the continual capacity to manipulate and update the reference data upon which the systems are built as the IT-enabled development of information sustainability. In our case study, the Algorithm Designer and Algorithm Tester are auxiliary software tools developed to afford trauma specialists the management of medical algorithms using a custom-built graphical user interface. The tools can be easily adapted to different clinical environments. The Algorithm Designer and Algorithm Tester are innovative tools that provide trauma specialists with an effective way of maintaining the TRR system and keeping it at the cutting edge of medical knowledge.

In such a mission-critical and time-critical domain, the knowledge base of the system must adapt to the evolving needs of users, and hence, a means to enrich the system's knowledge base must be provided. By allowing the end-users who are also SMEs to enrich the knowledge base, the system can grow in afforded diagnostic pathways in parallel with practitioner experience. This allows the system to conform to and incorporate contemporary medical practices. A non-proprietary input format reduces the barrier for entry to enrich and update the system's knowledge base. Furthermore, it allows practitioners—both internal and external to the institution—to reference the diagnostic pathways entered by clinicians who are well versed in the execution of treatments.

As more junior consultants join the trauma team, the TRR system is offered as a self-assessment and critical analysis tool for personal development. The use of the system in that capacity is voluntary, and once confidentiality is assured to the consultants, the TRR system is employed as a tracking and monitoring tool for their performance. The transcripts are then offered to them to self-assess their performance, also affording them the option to go through the transcripts with more senior staff to identify areas of improvement. When "non-typical actions" are performed by the new staff, the trauma team leaders can either incorporate them into the existing processes or add system prompts as contingencies against such actions.

Information sustainability requires information standards and information synergy in order to be applicable. Should compliance to standards not be met, and affordance for synergy not be offered, the enrichment of system data cannot take place.

8   Study Implications

We observed the impacts of ICT affordances on clinical information processing and clinicians in a time-critical environment. Our study has implications for both research and practice.

For research, our study extends the existing knowledge on ICT affordances in the IS literature, demonstrating that human variables in a clinical setting afford both predictable and unintended occurrences in ICT use, even among the most established systems and professional clinicians. This is particularly the case in IT-enabled solutions that simultaneously lead to new or improved capabilities, relationships and better use of assets and resources (i.e. enhanced capacity to act). In our model and consistent with prior studies, ICT affordances depict the relationships between the abilities of an individual and the features of the ICT within the context of the environment in which they function (Chad 2011). According to Chad (2011), there is a range of affordances in a clinical environment; his study focused on understanding the affordance threshold as theoretical constructs in the nomological network of affordances that help to explain the use of ICT as a function of the difficulty of acting on ICT affordances. We show that affordances and technology change are invariably linked; recognising that IT is increasingly building on the knowledge and skills of professionals and the day-to-day practices of sub-cultures. The processes used at The Alfred prior to the deployment of the TRR system were team-based, focusing on decomposing complex traumas into actionable steps using crisis management principles and communication. Given the linearity of human thinking, and the variations in the number of operators, backgrounds and expertise, errors of omission are a constant risk in such an approach. Hence, a system that affords feedback outside of linear

thinking processes would offer support and real-time error avoidance. This eventuated in the design of a decision-support system that could be deployed in the trauma bay. In such a system, the trauma team should be able to serve as the SMEs to enrich the system's pathways as they evolve and refine their practices.

The use of affordances to analyse the design of technologies explicitly can help suggest ways to improve their usability in practice (Gaver 1991). Our study discuss the development of information standards, synergy and sustainability pertaining to the actualisation of the affordance of an ICT tool that allows the organisation to evolve the ICT without having to engage software engineers. When used in conjunction with electronic patient history and records, the ICT displays potential applicability for teaching and training, as well as for audits and reviews. In addition, the location-independence of the system is a step towards better knowledge consolidation and dissemination among clinicians. The TRR system requires the manual data input to be performed by the TNL in the trauma bay. Hence, to ensure that this input process does not bottleneck the capacity of the system to support the trauma management, we performed further usability testing with the TNLs to refine the effectiveness and efficiency of the input interface. The testing took place in a usability lab environment with eighteen participants, of whom seventeen were TNLs working at The Alfred. Beyond the data input, the human variables introduced in a multi-disciplinary team, coupled with fluctuating patient conditions, resist the modelling of a standardised environment. These human variables result in the occurrence of errors even among established and experienced trauma centres and professionals. Furthermore, we developed and discussed the impact of the Algorithm Designer, a component of the ICT that allows clinicians to enrich and refine the processes supported by the ICT. Based on the analysis of the preliminary and secondary data, the pragmatic results of the ICT use indicated a reduction in the errors made by emergency staff by over 20%.

9   Conclusion

In this paper, we present a case study of the Trauma Reception and Resuscitation project at the Trauma Centre of The Alfred Hospital in Melbourne, Australia. In this study, we observe the actualisation of ICT affordances in a decision support system that is designed for better information processing. Specifically, our stage-wise model addresses a knowledge gap surrounding how ICT afford the development of information standards, synergy and renewal in order to reduce error rates in time-critical clinical practices. We show that ICT affordance focuses on the strengths and weaknesses of technologies with respect to the possibilities they offer to the people who might use them. This study represents the first step to better understanding how ICT affordances enable information processing in time-critical clinical practices; we are working towards the conduct of future studies on adapting the ICT for multi-national surgeon training and evaluations, and as a means to track and monitor procedures for accountability in cases of morbidity and mortality.

10 Acknowledgements

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