The Effects of Timing and Collaboration on Dependability in the Neonatal Intensive Care Unit

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1 Introduction

Computer-based systems are now routinely deployed in many complex dynamic domains, such as aviation and industrial process control. The critical nature of these systems means that their operators rely on them to do the right thing at the right time when called upon. In other words, they are expected to have a high level of what Laprie (1995) defines as dependability. To date dependability research has largely focused on developing techniques for improving the dependability of hardware and software in safety critical applications (e.g., Leveson, 1995). Dependability, however, is a property of the whole socio-technical system: people, computers and context. It is therefore important not only to understand these components, but also how the interactions between them affect dependability.

A wealth of research into human-machine interaction (HMI) has emerged over the last two decades (e.g., see Baecker & Buxton, 1987; and Baecker, Grudin, Buxton, & Greenberg, 1995). One obvious aspect of HMI that affects dependability, is the temporal properties of the interaction. Delays in system response times, for example, can make tasks more complex, and may lead to errors (Johnson & Gray, 1996). Such issues are present in most complex dynamic domains, but particularly in real-time systems, including medicine (e.g., Combi & Shuhar, 1997).

This paper considers how timing issues in HMI affect dependability in one specialised branch of medicine: neonatal intensive care. A case study was carried out in the Neonatal Intensive Care Unit (NICU) at St James' University Hospital (SJUH), Leeds. An expert system, FLORENCE (Fuzzy LOgic for REspiratory Neonatal Care Expert), is being developed at SJUH (Tan et al., 2003) to help less

experienced staff make decisions about changes to the ventilators that are regularly used in treating premature babies.

One of the goals of the study was to identify any timing issues involved in the current socio-technical system that implements the practice of neonatal intensive care. More particularly, the aim was to identify and analyse those aspects of timing that affect how staff interact with the equipment in the NICU which places requirements on the design and use of FLORENCE. Once FLORENCE is in place, the dependability of the new system (including FLORENCE) should be at least equal to the dependability of the system without FLORENCE.

Section 2 of the paper provides an overview of the NICU environment at SJUH and an overview of the case study. Sections 3 and 4 highlight and analyse the timing and collaboration issues identified by the study and how they contribute to the dependability of the system of patient care. Section 5 examines how the introduction of FLORENCE could affect the timing and collaboration aspects of dependability. Section 6 briefly discusses the completeness of the case study methods in identifying timing and collaboration issues and considers the available alternatives. Finally, Section 7 summarises the work and suggests how it could be extended in the future to evaluate the impact of FLORENCE.

2 The Neonatal Intensive Care Unit

When a premature baby arrives in the NICU it is often placed on mechanical ventilation to help it deal with respiratory ailments, particularly Respiratory Distress Syndrome (RDS). This is a self-regulating disease, caused by the lungs not having developed sufficiently to produce the levels of surfactant required to facilitate gaseous exchange during respiration (e.g., Rennie & Roberton, 2002). The main aim during the period of ventilation is to stabilise the baby, such that its blood gas and pH levels remain within some predefined range. These parameters which are continuously monitored using a Neotrend multi-parameter intra-arterial sensor (Philips, 2001), cannot be directly controlled. They are affected by the baby's respiration, however, which is controlled using a Babylog 8000+ ventilator (Bartholomew, Newell, Dear, & Brownlee, 1994).

Much of the front line care of the babies is performed by nursing staff and junior doctors (Senior House Officers, SHOs). The SHOs normally only work in the NICU for six months as part of their job rotation. In general, the SHOs perform most of the interventions on the ventilator in acute situations where the baby has RDS, calling on more experienced members of staff as appropriate. One of the goals of FLORENCE is to empower the front line carers by helping them to more rapidly learn to make correct decisions about which interventions to make.

A Cognitive Task Analysis of the work in the NICU was performed in three stages (for full details of the methods see Baxter, Monk, Tan, Dear, & Newell, Submitted). First, domain and context familiarisation was carried out. Second, the Critical Decision Method (CDM; Klein, Calderwood, & MacGregor, 1989) was used to analyse decisions surrounding use of the ventilator. Third, naturalistic observation of the use of the ventilator in situ was carried out. These stages are briefly summarised below.