# Part II

# A Field Study in Anaesthesiology

# 3 The Domain of Anaesthesiology: A Description and a Work Analysis

– "What, Doc?! 500 bucks for putting me to sleep?"
– "Well, it only took 50 to do that. But it took 450 to wake you up."

—*Anaesthesia anecdote*

[the assumption] that we will never fully understand the connection between brain and consciousness ... appears to overlook that consciousness is routinely interrupted by general anesthetics. The loss of consciousness under anesthesia and the later recovery of it can, in principle, surely be elucidated as thoroughly as any other drug-induced changes.

—*B.R. Fink, 1993*

When starting a field study, a detailed analysis of the studied domain is both inevitable and necessary for collecting meaningful data and for understanding the behaviour of the inhabitants of that domain (Rasmussen *et al.*, 1989; Bisantz & Vicente, in press; Simon, 1969). This is similar to the case in which one enters a foreign country. In order to effectively communicate with the inhabitants and to understand the activities observed, one has to learn that country's native language, cultural codes, history, geography, etc. For a field study in the domain of anaesthesiology, this requirement of knowledge and analysis is translated into the need to answer the following questions:

- What is anaesthesia?
- Who are anaesthesiologists (what training/education does one need to become an anaesthesiologist)?
- What are the major goals and means of the job?
- What are the typical task sequences in the job?
- Who are the major players in the domain of anaesthesiology and how do they interact with each other?
- What are the constraints placed on the anaesthesiologist?

This chapter answers these questions by a work analysis of the domain of anaesthesiology. It also discusses the appropriateness of the domain for carrying out a field study of problem solving in dynamic and complex work domains. The sources for the analysis and descriptions in this chapter came from textbooks (*e.g.*, Carrie, 1982; Ravin, 1981; Chung & Lam, 1990), journals in anaesthesiology (*e.g.*, *Anesthesia & Analgesia* and *Anesthesiology*), conversations with anaesthesiologists, and personal observations inside and outside of operating rooms (ORs).

## 3.1 Overview of the domain of anaesthesiology

Like any other medical field, the domain of anaesthesiology poses a great mystery to an outsider.[1] This section provides an overview of the domain, starting with a fictitious case which is intended to illustrate typical activities in anaesthesia for the majority of cases.

### 3.1.1 A casual observer's account of an anaesthetic

*It is 4:00pm. After leaving the last patient of the day to a recovery room nurse, Dr. Chung,[2] a staff anaesthesiologist, goes to the OR front desk to check the next day's assignment. Two cases are listed for him: a cholecystectomy scheduled for 2 hours and a laparotomy for 4 hours. He then goes up to the patient floor and requests both patients' medical records before visiting them. The patient in the first case, Mrs. Bartlett, looks rather weak. The partial pressure of carbon dioxide ($P_{co2}$) in her arterial blood gas test is very high (60 $mmH_g$), signaling that the patient has a very bad lung. He is quite worried about her. The second case patient, Mrs. Stone, has a pancreatic mass but otherwise is healthy. Dr. Chung gives medication orders for both patients after filling out pre-operative assessment questionnaires and confirming with the patients some of the information on the medical records.*

*At 7:45am on the following day, Dr. Chung arrives at the OR. The nurse gives him a note that the case order has been switched for some reason. He checks monitoring and delivering equipment to be used, and runs self-diagnostics programs on the anaesthesia machine, while two nurses prepare electrocardiagram (ECG) leads and surgical equipment. Then he draws up syringes, labels them and prepares induction equipment. At 8:00am, a nurse informs him that the patient, Mrs. Stone, has arrived outside OR. He quickly positions Mrs. Stone on the operating table and hooks up ECG leads, automatic blood pressure cuff, and pulse oximeter probe with the help of a nurse. All three measurements are displayed and auditory beeps can be heard, signaling the patient's heart rate and oximeter reading. Dr. Chung puts an intravenous (i.v.) infusion catheter and an invasive arterial blood pressure catheter in the patient's arms. The patient is then masked and breathes through the mask.*

*After a visual inspection of the patient, monitors, and equipment around him, he injects anaesthetics using syringes already drawn up into an i.v. port, and opens the vapourisor of the anaesthetic agent. Soon after verifying that the patient is asleep, he puts an endotracheal tube (ETT) into the patient's trachea via the mouth and uses a stethoscope to listen to the patient's chest. The patient is anaesthetised and the breathing airway is secured.*

*He then puts on a surgical gown and performs a brief surgery on the patient's right external jugular vein to put in the central veinous pressure (CVP) monitor catheter, while the surgical team is draping the patient and waiting for the signal from the anaesthesiologist that the surgery can commence.*

*It is 8:40am, about an hour after Dr. Chung arrived at the OR and 40 minutes after the patient was brought to the OR. The surgeon now starts preparing the surgical area on the patient's belly and is ready to cut to expose the surgical site. Dr. Chung sits down, charting the anaesthesia progress so far while scanning back and forth between the surgical site and monitors. The case progresses smoothly. Dr. Chung adjusts the vapourisor settings now and then, chats with the nurses and the surgeon, answers phone calls regarding some organisational matters. At 11:06am, the surgeon informs him that a pancrectomy is to be performed as the pancreatic mass turns out to be cancerous, and the second case is to be cancelled as the first case will last much longer than the original booking. Dr. Chung is relieved because he does not have to do that case in which the patient's condition is so worrisome. He repeats doses of muscle relaxant and narcotics, and maintains the fluid infusion as the case goes on.*

*At 3:20pm the surgeon starts closing up the wound. 10 minutes after that, the surgery finishes. The anaesthesiologist injects a reversal dose for the muscle relaxant, turns off the vapourisor, and waits for the patient to gain consciousness. He watches the patient's chest movement and examines the pupil sizes. Verbal commands are used to wake up the patient. At 3:38pm, the patient wakes up. The anaesthesiologist pulls out the ETT tube and puts on the breathing mask. A stretcher is brought in and the patient is then transported to the recovery room, where Dr. Chung is greeted*

[1] Abbreviations used can be found in Appendix A.

[2] Names used here (Dr. Chung, Mrs. Bartlett, and Mrs. Stone) are fictitious.

*by a recovery room nurse and an anaesthesiologist. Duties are transferred and an anaesthetic case of Dr. Chung's finishes smoothly and uneventfully.*

### 3.1.2 What is anaesthesia

Literally, the word "anaesthesia" means "without feeling." *Webster's Ninth New Collegiate Dictionary* defines it as the "loss of sensation with or without loss of consciousness." The initial purpose of an anaesthetic was to remove pain from surgery, but later it was found that suppressing consciousness (and memory) and muscle reflex were equally as important as removing pain. So even though the popular image of the anaesthesiologist's job is no more than putting someone to sleep during a surgery, anaesthesia actually consists of three components—the so-called anaesthesia triad—narcosis (sleep), analgesia (pain relief) and muscular relaxation (relaxation). The purpose of an anaesthetic is to put the patient into such a state that he or she is unconscious, amnesic, painless, and motionless (in and around surgical sites). In itself, an anaesthesic has little intended therapeutic value.

Two types of anaesthesia are commonly performed—regional and general, depending largely on whether the patient loses consciousness. While regional anaesthesia blocks pain from transmitting to the brain, general anaesthesia is more versatile and accomplishes the anesthesia triad in various compositions. Among the two, general anaesthesia counts for the majority of cases, and this field study focuses only on general anaesthesia.

In general anaesthesia, anaesthetics can be delivered to the patient through two avenues: intravenous or intramuscular injection via the circulatory system, or inhalation via the respiratory system. Often these two avenues are used jointly to achieve the desired patient status.

Figure 3.1 shows a layout of a typical operating room (OR). The layout shown here is for cardiac surgery but other ORs are more or less the same (without the perfusion machine and the perfusionist, of course). When the use of anaesthetics in surgery started 150 years ago, the control of the triad was through a single variable: dripping ether under the patients' nose. The monitoring of the patient and the achievement of the triad was done by clinical signs: palpation, pupil sizes, sweating, and so on. Advances of the science and practice in anesthesia have developed a well-recognised medical specialty: anaesthesiology. "No longer is the anaesthesiologist only an averter and annuller of surgical pain. The anaesthesiologist works hand in hand with the surgeon and other medical colleagues to evaluate and prepare patients before surgery, and is the patient's primary-care physician during the intraoperative period, and has direct input into the postoperative management of the patient" (Chung & Lam, 1990, p. 2).

Present and future surgical procedures put forward more and more challenges to anaesthesiologists, as patients tend to be very old, very sick, or new born. As well, surgical procedures tend to be very complicated, as in the case of organ transplants and of open heart surgeries. At the same time, developments in anaesthesiology are providing more tools and ways of doing the job. More devices for monitoring the patient are being introduced; more options are provided to produce, and to allow better control of, various aspects of anaesthesia. Providing the conditions for surgery is, although originally the primary goal, probably no longer the most difficult aspect of the anaesthesiologist's tasks.

Over years of development, anaesthesiologists have expanded the scope of their practice to include intensive care work and pain management, although the primary focus of anaesthesiology is still to provide a motionless surgical field and maintain optimal physiologic function during and after surgical procedures. That is also the focus of the present study.

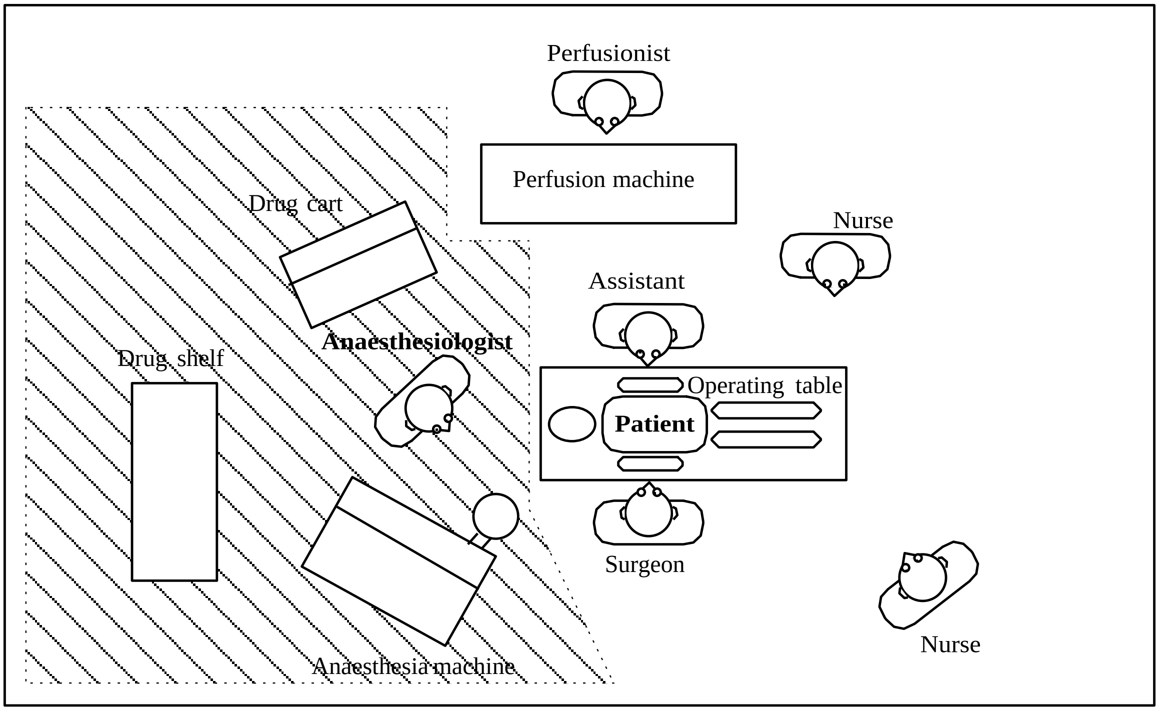



Figure 3.1: The layout of a typical operating room (OR). The observer's positions are shown in the shadowed area. The perfusionist and the perfusion machine are only for cardiac surgeries.

### 3.1.3 Anaesthesiologists: Who are they

An anaesthesiologist[3] is a medical doctor (MD) who has a specialisation in anaesthesiology. The education and training in anaesthesiology currently includes a four year residency (after four years of medical school). During the residency, the training mainly takes the form of an apprenticeship: the resident practices under the direct supervision of a staff anaesthesiologist. At the same time, theoretical background is strengthened through reading and discussion with the staff with regard to the cases being practiced. Towards the end of the residency, most residents are able to make their own decisions, although officially the supervising staff is still in charge, regardless of whether or not the staff is present in the OR. Residents in general rotate among hospitals to gain experience in various specialties within the practice of anaesthesiology. While in any one hospital she or he is assigned to different kinds of cases.

Apart from practicing with a staff member, residents are also expected to participate in "case rounds," in which cases, either personally experienced or reconstructed, are presented. The presentation is often in original temporal order and the presenter pauses and asks members of the audience to give their assessment of situations, their choices of solution and justifications, and their comments on the performance of the participant (*i.e.*, the anaesthesiologist who actually performed the case).

The end of residency and the start of attending practice do not mark the end of training. Rather various formats of training continue to enhance performance, such as (1) attending short courses, (2) reading text books, professional journals, and case study reports,

[3] In English-speaking countries other than the United States, the anaesthesiologist is commonly called an anaesthetist. Using the name "anaesthesiologist" is necessary when referring to someone who is a physician, not just anyone who administers an anesthetic. In Canada, where the current field study was conducted, only physicians can perform anaesthesia. Thus every anaesthetist here is an anaesthesiologist.

(3) reading instruction materials from pharmaceutical manufacturers, and (4) informal communications (sharing anectodal experience). By the time one starts professional practice, an anaesthesiologist has been exposed to a large number of cases. The expertise acquired during the residency includes not only practical experience, but much theoretical knowledge as well.

The fact that an anaesthesiologist is an MD is important in the micro-social environment in the OR. Historically the surgeon has played a dominant role in the OR, and many surgeons still feel that way today. The interactions between the surgeon and the anaesthesiologist have become complex and the rivalry between the two is not always subtle. The impact of social relationships on the way in which the anaesthesiologist and the surgeon communicate with each other is an important determinant of the anaesthesiologist's behaviour in the OR. The focus of the current field study, however, is not on sociological issues, *per se*, although they are hard to ignore.

## 3.2 A work analysis of the domain

### 3.2.1 The goals of the anaesthesiologist

The anaesthesiologist has two primary goals during a surgical operation: (1) safe-guarding the patient—*i.e.*, sustaining life and preventing injuries; and (2) providing necessary surgical conditions. In a seemingly self-contradictory manner, the anaesthesiologist has to alter the patient's physiology (*e.g.*, pain reflex) to fulfill these two goals. Along with surgical procedures, in order to produce surgical anaesthesia, the anaesthesiologist imposes substantial disturbances on the patient's physiology and anatomy, and it is in general the responsibility of the anaesthesiologist to maintain various balances in the patient's body (*e.g.*, those of the respiratory, metabolic, cardiovascular, renal, and central nervous system).

Most of the intervention done by the anaesthesiologist is pharmaceutical, that is, through drug input. All anaesthetic drugs are potentially toxic. The "art" of anaesthesia is thus to balance between the edge of intoxication and the amount of drugs, in the best interest of the patient, to realise sufficient narcosis, analgesia and muscle relaxation. To achieve these, the anaesthesiologist must be a competent physician and clinical pharmacologist, with a broad knowledge of surgery and the ability to utilize and correctly interpret a variety of monitoring devices.

Different surgical procedures require different proportions of the components in the anaesthesia triad. Different patients have different physical status and respond differently to drug inputs. These and other factors demand different techniques for producing the anaesthesia triad. Therefore, anaesthesiologists must combine a knowledge of the patient's disease, the drugs taken, the demands of the operation, and the patient's preferences to arrive at a proper choice of techniques.

### 3.2.2 The general procedure of an anaesthesia case

The procedure of anaesthesia varies greatly in terms of the duration, the method of producing the anaesthesia triad, the equipment used, etc. There is no prescribed, fixed step-by-step procedure that one should follow. However, there are some general similarities across the majority of anaesthetic cases.

The anaesthesiologist's involvement in a surgical case can be divided into four phases: (1) pre-operative preparation, (2) induction, (3) maintenance, and (4) emergence from anaesthesia and/or handing over to the staff in the recovery room. Analogy has been made between the anaesthesiologist and the airplane pilot (*e.g.*, Gravenstein, 1982) largely because of the similarity of these four phases to the sequence of preparation, take-off, cruise, and landing.

### Pre-operative preparation

A typical case starts with the assignment, which is a request from the surgeon[4] for the following day, and is often given by the name of the planned surgical procedure, the expected length, and the room number. The anaesthesiologist then requests medical records of the patient and reads them if available. The visit to the patient (the so-called pre-op visit) is done for physical examination and questionnaire administration. Medication orders (the so-called pre-med) are frequently given after the visit. For some surgeries the patient is not admitted to the hospital until the day of surgery and the pre-operative assessment is done just before the patient is brought into the OR. The anaesthesiologist then makes up a so-called anaesthetic plan that specifies what will nominally be done to monitor the patient and to achieve anaesthesia.

Before the patient is taken to the OR, the anaesthesiologist prepares for the case by setting up equipment and drawing up syringes. Special equipment and drugs not present in the OR are ordered also. The preparation typically takes 10 to 40 minutes.

### Induction

When the patient is brought into the operating room, various monitors are attached to the patient (*e.g.*, ECG monitor, pulse oximeter, etc.) and an i.v. line (occasionally more than one) is set up for delivering fluids and drugs. Invasive blood pressure (*e.g.*, arterial pressure) measurement is often established before the patient is anaesthetised.

The objective of the induction phase is to bring the patient, as quickly as possible, to an anaesthetised condition so that the surgery can commence.

During the induction period, the patient is anaesthetised and the breathing airway secured. Most of the time a tube (ETT) is inserted into the trachea (windpipe) to protect against airway obstruction and aspiration, and/or to apply positive airway pressures. A typical induction sequence is as follows, although variation in this sequence is large:

1. Pre-oxygenation: 100% oxygen is given to the patient and initial vital signs are measured and recorded;
2. Pre-curarisation: a subparalysing dose of non-depolarising muscle relaxant (*e.g.*, *d*-tubocurare) is injected;
3. A test dose of the induction agent (*e.g.*, theopental) is given, followed by an induction dose;
4. Nitrous oxide-oxygen mixture is given via the face mask, and may be given jointly with a volatile agent (*i.e.*, Halothane, Enflurance, or Isoflurane);
5. Succinylcholine is given to paralyse the patient;
6. An endotracheal tube (ETT, a breathing tube to protect the airway) is inserted with the help of a laryngoscope;
7. The position of the ETT is verified.

The entire sequence is typically completed within 10 minutes.

Still more invasive monitoring devices are often set up after the surgical anaesthesia is established, such as the CVP monitor.

The induction phase is a very busy time period in two respects. First, there are many *physical* activities to be carried out. To produce surgical anaesthesia, a number of drugs have to be given within a relatively short period of time. (It is common to see four or five drugs given within two to three minutes.) In the same time period, the anaesthesiologist intubates (*i.e.*, inserts the ETT into the patient's trachea), connects the breathing circuit, and sets up the ventilator and the vaporiser.

Second, there are intense *mental* activities. During the induction, the patient's physiological status changes dramatically and quickly. These changes are reflected in a number

[4] In a small number of cases the operation is not done by the surgeon but by other professionals, such as hemotologists in a bone marrow harvest. For the simplicity of presentation, the word "surgeon" will be used for all cases.

of modalities in different physical locations. To interpret these changes properly, the anaesthesiologist has to first establish a baseline reading by correlating redundant information sources, because each patient starts with a different physiological profile and responds differently to the drugs given. There are many ways that the induction procedure can go wrong, and thus, the anaesthesiologist must constantly check and recheck.

#### Maintenance

Once the patient is anaesthetised, the job of the anaesthesiologist is to maintain the patient's status, that is, the balance in various subsystems, and to accommodate the surgeon's demands on the patient's status (*e.g.*, body temperature, blood pressure and relaxation level). These are achieved by repeated or continuous drug injection, adjustment of ventilation and vaporiser settings, etc. Other observable physical activities usually include charting, re-arranging the workplace layout, and quite often, preparing for the next case (the pre-operative preparation phase for the next case). Physical actions needed for intervention are infrequent (along the order of every 10 minutes). A major task is to monitor the patient and the surgery. The anaesthesiologist constantly scans the workplace, the surgical site(s), and the patient. Surgical progress is of particular importance, as it gives cues about future surgical events and about the finishing time.

#### Emergence

Towards the end of the surgery, the patient emerges from deep anaesthesia and most likely regains consciousness and wakes up. In some sense it is the reverse process of induction. The emergence phase requires the anaesthesiologist to reverse the effect of anaesthesia as quickly as possible. This goal requires the anaesthesiologist to plan ahead during the earlier phases so that the reversal process will be swift.

Similar to the induction phase, the patient's physiological status changes quickly and considerably. However, because the anaesthesiologist has established baselines for interpreting various displays and clinical signs, this phase is usually not as stressful as the induction phase. Some of the monitors that were set up at the beginning of the case are removed. Others, such as i.v. infusion bags and oxygen mask, are made to be suitable for transporting the patient to the recovery room or intensive care unit.

### 3.2.3 The anaesthesia system

Recall that the major goals of the anaesthesiologist in the OR are to safeguard the patient and to provide the necessary conditions for surgery. What the anaesthesiologist does is to supervise the patient's physiological processes *during* the whole course of surgery within a range such that these two goals are fulfilled. It is with respect to this aspect of the skilled operator's responsibilities that the similarity is drawn between the task of anaesthesia and that of process control. In the following, the work environment of the anaesthesiologist is analysed as a process control system.

#### Components in the anaesthesia system

Five components can be identified in the work environment of anaesthesia: (1) the patient, (2) the anaesthesiologist, (3) other personnel (the surgeon, the nurses, the perfusionist, and assistants) that interact with the patient, (4) patient monitoring and drug delivery devices, and (5) drug carts, supply shelves, etc. that form the physical surroundings of the anaesthesiologist and that the anaesthesiologist can touch, see, and reorganise. Within a larger scope, the anaesthesiologist also interacts with other supporting facilities outside the OR (blood bank and laboratories), but, for the purpose of this study, these are not included in the analysis. In keeping with the analogy of process control, the anaesthesiologist is the *human operator* and the patient is the *plant* (Figure 3.2).

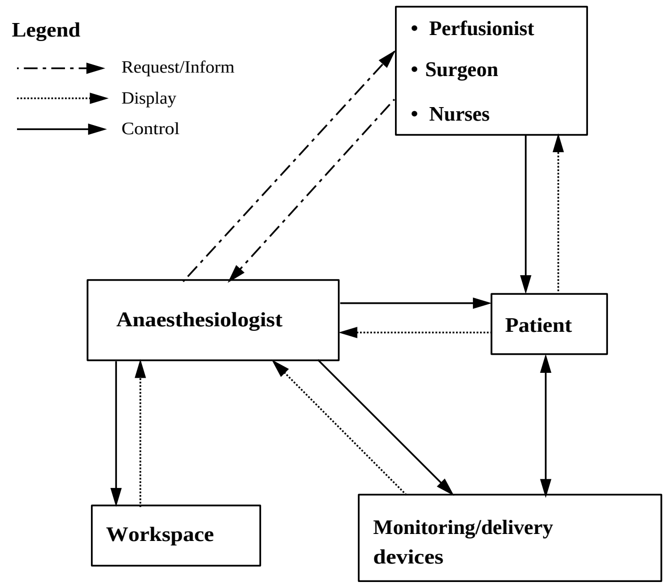



Figure 3.2: The anaesthesia system from the viewpoint of the anaesthesiologist. See a description of the relationships in the text.

From an engineering point of view, the anaesthesiologist can be looked upon as a systems manager; the patient represents a dynamic system or process whose variables are functions of time. During a surgical operation, these variables may become unstable and change rapidly. The anaesthesiologist must maintain the value of the variables within a range that allows the surgeon to work under optimal conditions and prevents the patient from becoming unduly stressed.

Below the interactions among the various components are discussed in turn (refer to Figure 3.2).

**The anaesthesiologist ↔ the patient.** This interaction is mostly for obtaining information. Direct interventions are rare. Clinical signs are obtained through direct observation of the patient, palpation, or stethoscopy. This source of information is direct, and thus judged to be very reliable. However, information obtained in this way may not be as diagnostic as that from monitoring devices. Surgical procedures often limit access to the clinical signs.

Observing the surgical site is particularly important, as what the surgeon does directly influences the patient's status. A glance at the surgical site gives indications of the surgical progress, which in turn tells the anaesthesiologist about the disturbance that the surgery is imposing on the patient, and what the surgeon will do next. Some surgeries expose a certain part of the anatomy that is particularly informative to the anaesthesiologist. For example, during an open heart surgery, the anaesthesiologist can see the heart's rhythm directly.

**The anaesthesiologist ↔ the equipment.** Monitoring and delivery equipment have become inseparable in the anaesthesia practice. Monitoring devices are used to monitor both the patient and the delivery systems. In this sense, the anaesthesiologist is supervising two self-driven processes: the physiological processes within the patient and the delivery processes. With more automation introduced into the anaesthesia practice, more delegating devices are being used by the anaesthesiologist, with the intention of reducing the workload.[5] The commonly used ventilator and automatic in-

[5]Although some of these devices have the potential of *increasing* the workload instead—see a research

fusion pumps are examples of such devices. With the sophistication of instrumentation in the OR, the interaction between the anaesthesiologist and the patient is becoming predominantly equipment mediated, given that the majority of patient information is from monitoring devices and the interventions made by the anaesthesiologist are largely pharmaceutical.

The basic modes of interaction between the anaesthesiologist and the equipment are:

- reading directly from displays. This may involve changing display modes or making specific requests (as in requesting automatic cuff readings).
- setting gas and fluid delivery devices. This includes setting ventilation parameters (rate, volume, pressure, gas ratio), vaporisor concentration level, fluid infusion parameters (normal saline fluid infusion rate and automatic drug infusion pump parameters), and adjusting the height of the fluid infusion stand.
- injecting a drug in bolus directly into an i.v. port and squeezing the infusion bag to increase fluid flow rate.

At the beginning of a case, the anaesthesiologist essentially configures the monitoring setup for that case. Deciding what invasive monitoring lines to use is often difficult and is part of the skill to be mastered. A compromise between informativeness and costs (invasiveness and convenience) has to be made. It is not uncommon to see that the anaesthesiologist gives up a monitoring variable because the difficulty of setting up a monitor is too great, or the monitor does not work properly.[6]

**The anaesthesiologist ↔ other personnel.** The OR is a cooperative work environment. Verbal and non-verbal communications among OR personnel are an important source of information for the anaesthesiologist. They often give the anaesthesiologist indications of the surgical progress, the intention of the surgical team, etc. In a coronary bypass surgery, for example, the perfusionist takes over the functions of the heart and the lung; the importance of close coordination between the anaesthesiologist and the perfusionist is apparent.

**The anaesthesiologist ↔ the workspace.** Often ignored in analyses of the anaesthesia system (*e.g.*, Meijler, 1987), the surroundings of the anaesthesiologist form an important workspace. This includes the drug cart and the bench area on the anaesthesia machine. The anaesthesiologist can place drugs, syringes, equipment, etc. on the workspace. This "display" characteristic of the workspace provides the anaesthesiologist a potentially important way to get (and to store) such information as drug input status.

**Other personnel ↔ the patient.** The input to the patient from the surgeon changes the anatomy and physiology of the patient and usually disturbs the balance in the patient's inner physiological world. Surgeons also have the potential to cause problems in patient measurement and drug delivery, such as pressing sensing tubes, disabling infusion lines, or pressing organs directly.

### An analysis of complexity of the anaesthesia system

There are many ways to characterise the complexity of a system. For the interest of studying human-machine systems, Woods (1988) suggests a four dimensional scheme as a framework for locating factors that make an operator's task difficult. In this scheme, the complexity of a system is characterised by four factors: *dynamism, interaction, uncertainty,* and *risk.*

report on this issue in a different domain by Kirlik, 1993.

[6] Standards of minimum monitoring vary among countries, and monitoring practices vary from hospital to hospital. In the hospital where the study took place, ECG, pulse oximeter, capnograph, inspire/expire gas monitors, and blood pressure cuff are used in almost every case.

In the following, the anaesthesia system is examined along these four dimensions. Domain text books, such as Ravin (1981), provide a good basis for this purpose.

**Dynamism.** Needless to say, human physiology is a dynamic, living process, with a large number of mechanisms to ensure the balances in its functional subsystems. These balances are usually maintained so well that the body appears to be static (as in the case of body temperature). Under conditions of anaesthesia and surgery, however, the mechanisms maintaining various balances are disabled or impaired, and external forces are present, either to help to maintain these balances or to work against the mechanisms. These changes are subtle at times but often produce drastic results. The surgeon, for example, can accidently cut a major vessel and instantly put the patient's life in danger.

The OR as a working environment is changing as well. For example, measuring and drug delivery devices can be dysfunctioned by intentional or unintentional acts of other personnel in the OR. As a case progresses, the goal of the whole OR team (including the anaesthesiologist) may shift as the result of the events which have occurred. The anaesthesiologist therefore has to continually reassess situations in terms of the general goal—the well-being of the patient—and adjust plans accordingly.

One of the consequence of the dynamic nature of anaesthesia is that the anaesthesiologist does not have the luxury of prolonged therapeutic trials with a variety of drugs and supporting measures. He or she has to stabilise the patient even at times when the cause of the instability is unknown (*e.g.*, Xiao *et al.*, 1992). In addition, the treatment, in itself, often complicates the diagnosis. (Cook *et al.*, 1991; Gaba, in press).

**Interaction.** Traditionally the human body is viewed as being divided into several complicated, interconnected subsystems (*e.g.*, cardio-vascular, respiratory, nervous, and renal systems), as illustrated in Figures 3.3–3.5, which have been constructed for the present study both to illustrate these classification schemes and to emphasise further the complexity of the anaesthesia work domain. In addition to highlighting the large number of degrees of freedom in these particular physiological systems, these figures also illustrate a number of the inter-relationships among the components in the functional subsystems. That is, the fact that subsystems are divided functionally does not imply that the relationships between them can be decoupled. On the contrary, these systems interact in complicated and often unintuitive manners. Symptoms of hypotension (low blood pressure reading), for example, may relate to airway problems, or a drug overdose, or a dysfunction of the anaesthesia machine. As another example, renal dysfunction can result in a deficiency of gas exchange in the lungs. Because of this interacting nature, the anaesthesiologist has to be vigilant about the multiple factors that can operate simultaneously to produce a surfacing symptom. The interactions also prevent separation of causes and consequences, and poses difficulties for diagnosis and assessment of actions.

In addition to viewing the body in the traditional way, as represented by the many *functional* subsystems illustrated above, some of which share common *physical* media (*e.g.*, blood). Table 3.1 presents an alternative representation. According to this table, the task environment of the anaesthesiologist is depicted as a *means-end abstraction hierarchy* (Rasmussen, 1983). In a means-end abstraction hierarchy, the system in question is represented conceptually at several different levels of abstraction, depending on one's particular function purpose and/or immediate goals. A complete means-end analysis of the domain of anaesthesiology is well beyond the scope of the current field study. See the effort by Bisantz and Vicente (in press) for an example of a comprehensive means-end analysis for a process control domain.

**Uncertainty.** The capability of monitoring the patient's physiology is limited in many ways. Patient monitoring is hardly based on the information needs, but rather, on

| *Level of abstraction* | *Exemplary elements* |
|---|---|
| Functional purpose | Patient safety, efficiency of producing and reversing surgical conditions, social and professional status. |
| Abstract function | Total volume of fluid and circulation, ion balance ($pH$), metabolism, life process, depth of anaesthesia. |
| Generalised functions | Cerebral oxygenation, cerebral perfusion versus mean arterial pressure, oxygen transport, peripheral resistance and perfusion, fluid distribution, homeostasis and autoregulation. |
| Physical functions | Pharmacokinetics, gas binding curves, Laplace relationship, oxyhemoglobin dissociation curve, cardiac output function. |
| Physical form | Anatomy, clinical signs, patient's movement patterns, electrocardiogram (ECG) waveform, $CO_2$ trace, surgical site. |

Table 3.1: Means-end abstraction hierarchy for the anaesthesia system. In a means-end representation, a system is described simultaneously at several levels of abstraction. Each level relates to its neighbours in conceptual means-end relationships: the higher level answers the question of "why" while the lower level the question of "how." The top level represents the system in terms of ultimate goals; the bottom level represents the system in terms of physical appearance and resources. (See Rasmussen, 1983.)

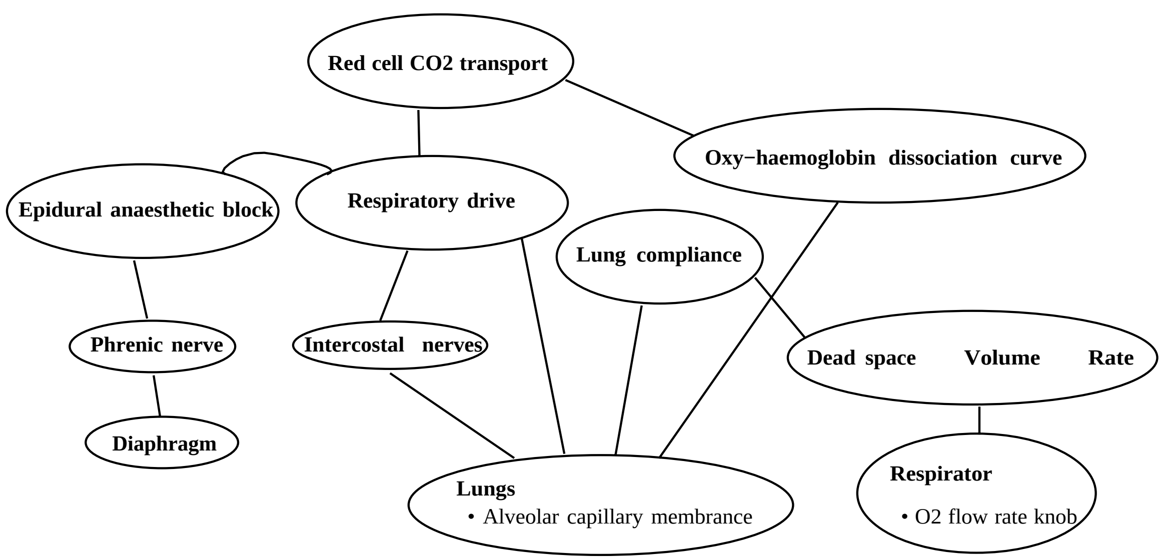



Figure 3.3: A subset of causal links in the respiratory system.

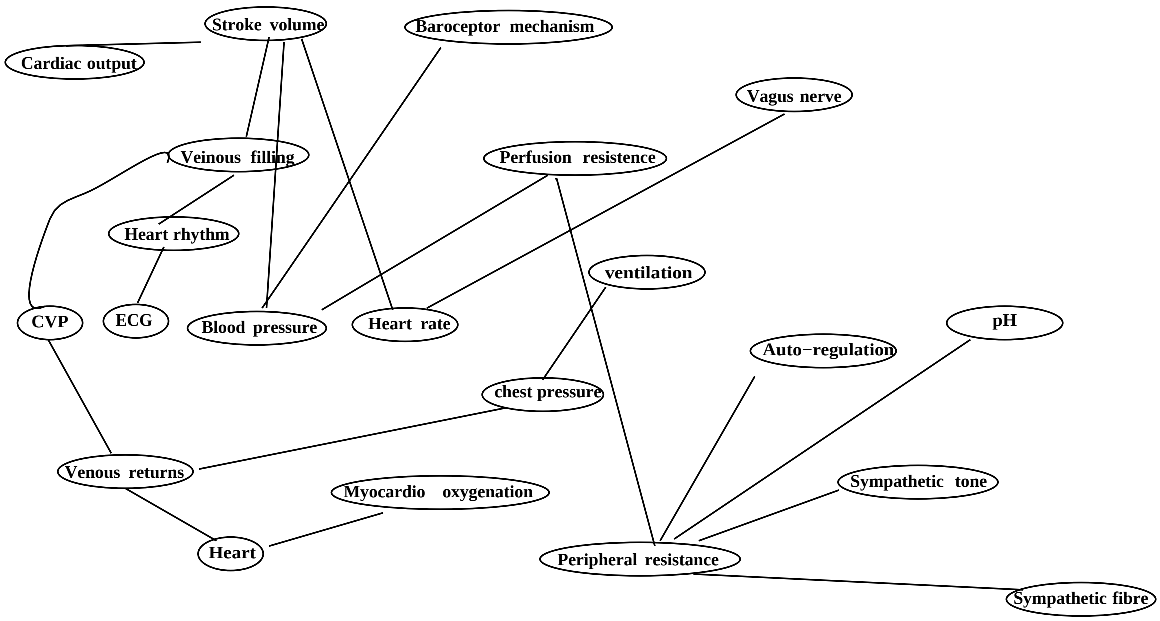



Figure 3.4: A subset of causal links in the cardiac system.

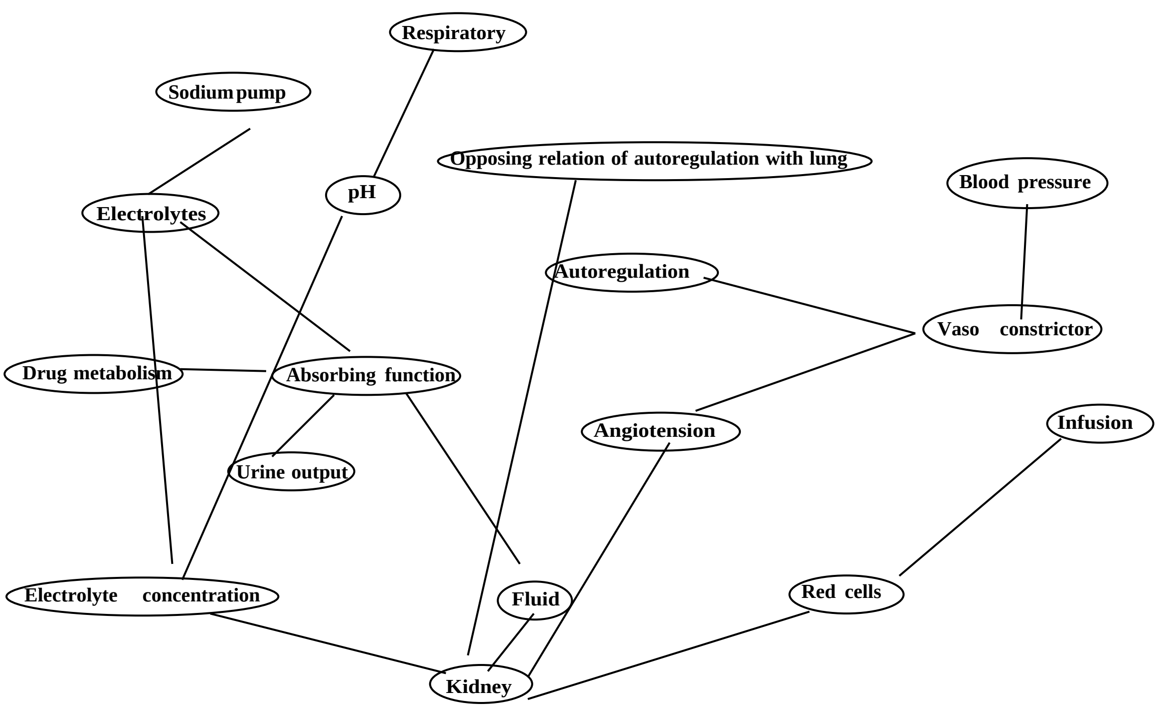



Figure 3.5: A subset of causal links in the renal system.

availability and accessibility. Some of the methods of monitoring are too invasive to the patient, or too costly, or take too long to set up. Therefore, their usage has to be balanced against their merits. Some monitoring variables can be obtained only in a discrete manner with considerable delays (*e.g.*, laboratory analysis of blood gas). The data gained are often incomplete, erroneous, and imprecise. The patient usually has some concurrent diseases, and sometimes has had previous surgeries that changed the anatomy (as in the case of valvular graft). He or she can also have diseases or drug reactions that are unbeknownst to the anaesthesiologist.

Similarly, the effects of drugs are known only to a certain level of precision and vary from case to case. There is a large variance across the patient population as well. Each operation is different from others in some aspects and dosages have to be adjusted accordingly. Our understanding of physiology and pharmacodynamics is only partial. (There are, for example, four rival hypotheses that explain the action of anaesthetics.) The case of blood pressure, the most commonly measured variable, exemplifies the difficulties of interpreting the observed readings:

- there is a lack of accuracy in the basal (control) blood pressure reading,
- there is a lack of the accuracy in the blood pressure determined during the operation,
- there is a lack of criteria for determining normal blood pressure versus hypertension in a particular patient, and
- it is difficult to judge whether or not to treat hypertension

In spite of these difficulties, "[i]n the absence of easily applicable direct flow measurements of regional circulations or accurate measurements of tissue oxygenation, the blood pressure determination remains our best indicator of cardiac output" (Ravin, 1981, p. 53).

Another aspect of uncertainty is the delay involved in measurement and assessment of intervention. Body temperature and perfusion status, for example, manifest underlying problems only slowly (often along the order of 30 minutes). Some interventions (such as insulin to reduce potassium level) can take 10 minutes or more to assess their effectiveness. The delays in measurement and assessment aggravate the impact of measurement imprecision and knowledge deficiency in physiology and pharmacology.

**Risk.** Almost all things that the anaesthesiologist does have some associated risk. Rare drug overreactions and other infrequent but drastic side effects do occur.[7]

One unique feature of anaesthesiology as a medical practice is the legal factor. All actions (and inactions) are under the supervision of legal requirements. The patients' wishes and preferences are important factors that influence the anaesthesiologists' decisions. The "best" solution may not be used simply because the patient has expressly rejected it (*e.g.*, as in the case of blood transfusions to a Jehovah's Witness). "The presence of risk means that one must be concerned with rare but catastrophic situations as well as with more frequent but less costly situations" (Woods, 1988, p. 130).

## 3.3 The anaesthesiologist as a system supervisor

In the current field study, the task environment of anaesthesiologists is taken as a "laboratory" of studying the activities of practitioners in naturalistic settings. Because of this, one has to be aware of the uniqueness in the studied domain, as well as those properties that are shared by other domains. In this section, the domain of anaesthesiology is compared with

[7] It is said that anaphylaxis, a severe form of overreaction, happens only once or twice in an anaesthesiologist's career.

domains in aviation and industrial process control in order to highlight both the similarities and uniqueness of the domain of anaesthesiology.

Often the anaesthesiologist is, as already mentioned, compared with a pilot (*e.g.*, Gravenstein, 1982). Specifically, the induction phase corresponds to the take-off phase, the maintenance to the cruise, and the emergence to the landing. This viewpoint can also be backed up by observation of the anaesthesiologist's behaviour in the OR (McDonald & Dzwonczyk, 1988; McDonald *et al.*, 1990; Gaba & Lee, 1990). During the induction and reversal phases, he or she is usually very busy, in terms of both observed actions and cognitive demands. Between these two phases, however, maintaining anaesthetic status is usually a "quiet" phase; the system needs only occasional intervention and the major task is monitoring.

The individual tasks of an anaesthesiologist can also be compared to those of a process controller. The patient's physiological system functions under the supervision and the control of the anaesthesiologist. Through various monitors and clinical signs, the anaesthesiologist gains access to the patient's internal dynamics. However, the observation is not always direct, and integration of information from various sources is needed. Clinical experience and inference are necessary in the interpretation of the observed data. Intervention is decided based on a number of factors and is implemented in various forms, although mainly pharmaceutical (*i.e.*, drug, fluid, and vapour input, as opposed to physical manipulation).

### 3.3.1 Similarities

Specifically, the following similarities can be drawn between a process control task and anaesthesia:

***Little physical activity.*** For a large portion of the time the anaesthesiologist exhibits few observable activities and these activities are largely monitoring and "fine tuning" the patient's status.

***Supervisory control.*** The anaesthesiologist's actions mainly comprise regulating and intervening the internal dynamic process of the patient's body, rather than carrying out any parts of the functions of these dynamics. In the same manner, the anaesthesiologist's control over gas and fluid delivery devices is supervisory; he or she only sets parameters.

***Internal states not observable.*** The internal dynamics of the patient are usually unobservable; the anaesthesiologist relies on measuring equipment to get information about the patient's status and on mediating devices to apply controls to the patient.

***Compensatory role.*** The anaesthesiologist is supposed to compensate for any disturbance and dysfunction in the whole system, including both internal, physiological and external, equipment-related failures.

These properties are among the key features of many supervisory control systems, and we should expect that there will be significant similarities between the behaviour of anaesthesiologists and that of supervisory controllers in industrial processes.

### 3.3.2 Disparities

There are also significant differences between anaesthesia systems and industrial process control systems that could shape the behaviour of the anaesthesiologist quite differently:

***Partial understanding.*** Understanding and measurement of human physiology are impaired. In human designed systems such as nuclear power plans or airplanes, normal status is usually defined by the designer and correspondingly the human controller is provided with necessary information to fulfill his or her function. By comparison, human body is simply not "designed."

*Large variation of cases.* The degree of variation of cases is much larger than that of most man-made systems. The seemingly repetition of common surgical names give an illusion of similarity among cases. In fact, each patient in each case can represent a drastically different "plant" for the anaesthesiologist. It is his or her task to define, or to *discover*, the intended states during each operation. In other words, determining normality of patient's states itself can be a challenging task, which obviously adds to the difficulties of diagnosing.

*Configuring workplace in each case.* The anaesthesiologist has to set up the whole anaesthesia monitoring and drug delivery system for every case, whereas in a typical industrial setting, these are already set up in advance, and often tested for the human operator, and usually remain unchanged.

*Direct access to the patient.* Unlike most industrial process controllers, the anaesthesiologist has not lost direct access to the "plant"—the patient. In most cases the anaesthesiologist can always have direct access to clinical signs, such as the colour of the patient's skin. This source of information is direct and independent of equipment-assisted monitoring, thus providing important redundancy for calibration and cross checking.

*Critical roles of manual skills.* Manual skills remain important. Procedures like intubation and intravenous cannulation are key skills in anaesthesia, as is the ability to read clinical signs. Sitting behind control panels and exclusively pushing buttons have (fortunately) not been part of anaesthesiologists' work.

*Lack of well-established procedures.* Although there exist some algorithm-like procedures for some special situations (such as the Advanced Cardiac Life Support protocols), there are relatively few well-established procedures, and there is often a lack of interest in following those that have been established (Gaba & DeAnda, 1989). As mentioned above, it is a striking fact that an anaesthesiologist has to deal with a large variation of cases. This variation comes from differences among surgical procedures, and among patients themselves. Thus it is not feasible to have detailed algorithm-like procedures for the majority of scenarios. Compared with the operator in a power plant control room or a cockpit, there is little support for applying set procedures in the OR.

*Goal awareness.* Because of the non-designed nature of human physiology and the case variation, there are few specific procedures to ensure that the anaesthesia process is in fact safe (compared with most industrial processes, where operational procedures are specified). One can argue that the less specific the procedures, the greater the awareness of the goal, and thus that it might be less important to establish specific prescribed procedures (Rasmussen, 1983; Woods, 1984). This gives more reasons to believe that the behaviour of anaesthesiologists will reflect their *own* ultimate goals more often than will the behaviour of an operator in a domain where most activities are governed by company procedures.

In summary, although the anaesthesia system bears the basic nature of supervisory control systems, the above-mentioned comparisons should be kept in mind during the study of behaviour.

* * *

The practice of anaesthesia started as an "art" of balancing on the edge of death. The knowledge of physiology and pharmacology accumulated thereafter has changed part of the "art" into a science. The most unique feature of the practice, in comparison with other domains, is probably its richness in all three aspects: manual skills, knowledge, and judgment in a rapidly changing environment. These characteristics provide opportunities as well as challenges to the field study.

# 4 Direct Observation Study

> [The empirical approach] takes the world as we find it ... and then draws up statements about the regularities that have been observed to hold.
>
> —*W. Ashby, 1958, p. 2*

> There are nearly always many ways to solve any complex problem .... What we want is not to model a theory of the task, but to model the problem solver's theory of the task.
>
> —*E. Hutchins, 1983, p. 224*

I was bewildered by what I saw when for the first time I put on a green gown and stepped into an operating room (OR) where a brain surgery was underway. The flow of events rolled along smoothly; the surgeon, the nurses, and the anaesthesiologist were chatting lightly with no lack of humour. Were there *any* problems to be solved by the anaesthesiologist? Starting with this question, the field study began with a series of extensive field observations that lasted about two years.

In this phase, the observations were *direct*, in the sense that the observer was watching, mostly in the OR, the on-going events and activities of the subject[1]—the anaesthesiologist—and the cases were not mechanically recorded. Tests of using video and audio recordings were carried out, however.

One major purpose of the direct observation study was to understand *what* the subject was doing. Not only does this task of undertanding require basic medical knowledge about the domain of anaesthesiology, but also about the sociology in the micro-social environment: how nurses, the anaesthesiologist, and the surgeon interact with each other. The direct observation phase also aimed at exploring the domain of anaesthesia in relation to the goals of this field study: what kinds of problems are being solved by the anaesthesiologist. It should lay down bases for the following inquiries that would focus on one or a few critical aspects of the anaesthesiologist's cognitive activities. This chapter describes the procedures and the findings of the direct observation study.

## 4.1 Overview of the direct observation study

The direct observation study, as well as the other parts of the field study, were carried out in a *single* teaching hospital (The Toronto Hospital, General Division). The hospital accepts patients, mostly by referral, from surrounding community hospitals. Thus the cases

[1] Again, the word "subject" merely indicates someone who was being observed.

| *Case category* | *Number* |
|---|---|
| Coronary bypass | 1 |
| Delivery room | 4 |
| Emergency room | 1 |
| Esophagoscopy | 2 |
| Lobectomy | 3 |
| Laparotomy | 5 |
| Laparoscopy | 3 |
| Neurosurgery | 3 |
| Pain service | 2 |
| Tracheotomy | 1 |
| Vaginoscopy | 1 |
| Vascular surgery | 1 |
| *Total* | *27* |

Table 4.1: Cases in the direct observation study

are in general non-routine, and are considered to be more complicated than those seen in non-teaching hospitals. The department of anaesthesia itself is among the largest in the country, and provides services in operating rooms, recovery rooms, intensive care units, pain management, emergency department, and maternity wards.

For the following reasons, it was decided that a wide range of cases would be observed:

- narrowing down too early the scope of inquiry to a subset of cases is dangerous and may miss some important aspects of the anaesthesiologists' activities;
- the repetitions and variations among cases could direct the research attention to those patterns of behaviour that are relatively generic and less reliant on particular situations;
- the cases in the anaesthesia department vary considerably;
- each anaesthesiologist is expected to do a wide range of cases;
- a knowledge of the general practice of anaesthesia is important to the understanding of specific cases.

Most of the observations were taken inside operating rooms (see Figure 3.1, page 38, in which the shadowed area shows the locations of the observer), with some exceptions at the beginning. The subjects were a mixture of residents (two to four years of residency) and staff anaesthesiologists with various lengths of experience (ranging from two to thirty years). The cases observed varied from short, simple biopsies (less than 10 minutes) to lengthy, complicated heart surgeries (7 hours), and from pain service to emergency calls. These cases were not selected *a priori*, but arranged in an *ad hoc* manner due to the unpredictable nature of the case assignment. Table 4.1 shows the twenty-seven (27) cases that were documented, carried out by six (6) anaesthesiologists. There were about ten (10) other cases that were not documented.

For a field study in settings like anaesthesia, the first hurdle is to overcome organisational obstacles. In the OR, several parties are involved and obtaining explicit consent from all parties is difficult.[2] The field study adopted an informal approach in dealing with the consent issue. General permissions were obtained from the hospital administration and the Department of Anaesthesia for observation and audio-video recording. Specific permission was, however, still needed for each case. In most cases explicit consent was obtained only from the anaesthesiologist, and it was left for him or her to decide whether or not other

[2] The surgeon, for example, often arrives in the OR after the assistants have exposed the surgical field, which could take over an hour. Waiting for his or her consent would mean missing an important portion of a case.

parties in the OR should be consulted on the matter. During the field study, no opposition was encountered from any side (the surgeon, the nurse, or the patient). It is interesting to note that senior anaesthesiologists did not tell other parties about the field study, whereas residents usually informed the surgeon about the field study.

The contact person for the field study had been a crucial element. Not only was he a primary subject, but he also acted as a "touch-base" for finding subjects and a collaborator to convince anaesthesiologists to participate in the study. The contact himself was a staff anaesthesiologist at the Department of Anaesthesia. He holds a joint position at a biomedical engineering research institute, and has a doctorate degree in engineering.

## 4.2 Initial trials

The initial trials consisted of about ten observation sessions over a year. They were marked by observing a range of operations, some of which were non-elective surgeries. During these observations, no on-line recordings were done.

### 4.2.1 Some difficulties encountered

#### Domain barriers

Difficulties in understanding medical terms, vernaculars, trade names, and acronyms formed a barrier against effective communication with the subjects. This situation was exactly like an ethnographic study of a foreign culture. The activities observed were understood only in an isolated and fragmented manner. Questions were asked often because of the lack of a basic understanding of the anaesthesia practice. Attention was directed at activities that were sometimes of little significance to the practice. Finding out what questions (and when) to ask anaesthesiologists was a challenge in itself.

#### Limited amount of verbal activities

While an anaesthesiologist was doing his or her job, there was little verbal indication of what he or she was doing. Initially as a surprise, there was only a very limited amount of verbal communication even in an open heart surgery, in which the cooperation between the anaesthesiologist and the surgeon and the perfusionist was critical. The activities observed were basically physical movements. One got lost easily. Often there were a large number of seemingly relevant events to be attended to.

#### Large variations

The variations across cases were found to be on a much larger scale than what had been anticipated. It was clear that there was little repetition in procedures across cases. Even among the cases with similar steps, there were usually large differences in patients' conditions, in the preferences of the anaesthesiologist, and in the exact procedures used by the surgeon.

#### Multiple sites of activities

The activities of anaesthesiologists, though concentrated in the OR, were scattered around the hospital. As an example, they could run into the surgeon in the hallway and then talk to the surgeon about a case to be done the next day. As another example, they could talk to each other in the lounge during breaks about the case they were doing and obtain other anaesthesiologists' advice and comments. Inevitably there would be activities relevant to the anaesthesiologist's task that were missed by direct observations.

### 4.2.2 Sources of information found to be useful

The domain of anaesthesia affords many sources of information, both about the job of anaesthesia in general and about the activities of the anaesthesiologist in particular.

In the direct observation study, even though watching the on-going physical movements was an important component, it was only one of many sources of information upon which one could draw inferences about the mental activities concerning intentions, plans, diagnosis, and assessment. Some of these sources are discussed below.

Apart from the naturally occurring communications in the OR, it was found that informal conversations outside the OR (*e.g.*, those occurring in the coffee lounge among anaesthesiologists during breaks) provided information about attitudes and general approaches to anaesthetic problems. For example, one anaesthesiologist joked to another who often came in late: "today you're going to be in a new operating room and you're going to be panic and say 'oh my God, where did they put the epinephrine?' " Informal chats with the anaesthesiologists helped to understand the "culture" of the clinical environment and *insiders'* ways of thinking. These informal sources of information are important to the success of field studies like the current one, as they give guidance to the understanding of the (directly) observed activities, and often act as catalysts for forming hypotheses of behavioural patterns.

It was also found that there were usually some long time segments during which anaesthesiologists were relatively less occupied and were actually more than willing to talk about the case. Often they spontaneously explained what had happened, what was happening, and what they would do next. Informal interviews were also possible during these periods, in which the anaesthesiologist could be asked to give reports on the case in general or accounts of what had just happened.

### 4.2.3 Two methodological concerns

The initial trials also made apparent two methodological concerns for further studies. With the gradual familiarisation with the OR environment, it was possible to discern the directly observed activities. The behaviour started to appear meaningful and recurring patterns started to emerge (Cf. the ball game example cited on page 23). However, two questions arose as a result of the initial trials:

- Was the observed behaviour "natural"?
- How to parse the observed streams of behaviour?

#### Ensuring ecological validity

There are a number of reasons to suspect that the observed behaviour was less than natural, and thus the field study could lose its ecological validity as a result. First, the subjects were fully aware of the fact that they were being observed. They could do their job in ways that they would not do had the observer not been present. For example, they could "perform" their acts just for the sake of looking organised and skillful. However, the fact that anaesthesiologists invariably work in a team environment, and that in a teaching hospital they are often being watched by residents, eases this concern. Nevertheless, it was not possible to eliminate the subjects' awareness that the observer's sole purpose was to watch their every move.

Two measures were taken to minimise this effect. The subjects were told that the purpose of the study was not to evaluate their performance, nor to see if they had made any errors, but simply to observe their natural activities. It was also decided not to bring any recording devices into the observational study, as it was found that even paper and pencil recording could be intrusive. For example, in one case where a nurse approached the anaesthesiologist and discovered that an observer was holding a notebook, the nurse communicated in a noticeably different manner than she otherwise would have. Notes were made *after* each session to summarise the case, the major events, and the significant activities. This decision obviously reduced the amount of recorded details one could obtain, but at this stage the effect of any intrusive recordings was unclear, and it was necessary to first establish the base for judging whether or not the observed behaviour was natural enough to be useful. It was assumed that, however, after attending a sufficient number of cases, the observer should be able to know what type of behaviour is natural, and in which way the impact of the observer's presence could be reduced to a minimum.

Another reason for suspecting unnatural behaviour is the knowledge that the subject had about the field study. When starting with a new subject, he or she was informed about the purpose of the study. In particular, the subject was told that the study was to investigate problem solving in anaesthesiology. This was done to satisfy the consent requirement. Some subjects in fact specifically wanted to know about the field study.[3] In previously reported field studies (*e.g.*, Cohill, 1992), the subjects were usually not interested in the studies being conducted on them. This may have disadvantages but the advantage is that the behaviour observed is not affected by the knowledge of the objective of the study.

Although most of the subjects were more than willing to help, the briefing on the nature of the study inevitably to some degree changed how a case was done and, especially, how they reported to the observer. The observer had to be sensitive to possible biases both in the observed behaviour and in verbal reports. With the number of observed cases increasing and different anaesthesiologists being studied, the ability to detect most of these biases was built up. It was probably safe to assume that, after a period of observations, the behaviour, if disturbed, would return to normal, as the subject should be concerned more with his or her job performance than with whether or not his or her behaviour appeared in a certain manner to the observer. Similar challenges are posed to field studies in other disciplines (such as in ethnographic studies), and it seems that one of the most critical factors is the familarity with the subject domain and with the subject (Bernard, 1988).

### Disentangling behavioural streams

The behavioural stream observed in settings like the OR appears linear only to a recording machine. The initial trials clearly showed a basic nature of the anaesthesiologist's activities in the OR: the anaesthesiologist carries out several parallel threads of actions, which are interrupted by events in the OR. The anaesthesiologist could, for example, be in the process of preparing a drug when the surgeon requests that the operating table be adjusted. He or she could, in the middle of cannulating an i.v. catheter, pause and scan the monitors without noticeable external triggers.

To complicate the matter of disentangling this stream of interweaving threads of activities, deciding what was relevant to the task of anaesthesia was not always straightforward in the OR environment, simply because of the fact that the OR is a cooperative working environment. There are hardly any strict rules to specify what the anaesthesiologist should do. He or she could obtain help from a nurse when one is available, and delegate certain tasks to a nurse, or a resident (when in a teaching session).

These contingent and opportunistic characteristics of behaviour in naturalistic settings made it clear that seeking recurring patterns of behaviour at detailed spatial-temporal-linguistic levels was not possible and certainly not fruitful. For a direct observation study in a complex work setting, it is certainly the molar patterns of behaviour that deserve attention, due to the large variations at micro levels. After the initial trials, it was decided that an opportunistic approach was to be taken in the direct observation study. With increased exposure to the anaesthesiologist's activities in the OR, the behaviour appeared more and more organised, and different threads seemed to stand apart naturally. The continuum of behavioural streams could thus be segmented and segregated into large units of activities. Recurring, stable patterns of behaviour began to emerge.

* * *

[3] For example, one subject had taken courses in psychology and was quite interested in the details of the study. In general, it was found that anaesthesiologists are well-educated and are eager to learn.

The initial observation stage was thus a combination of getting acquainted with the subjects, the domain, and the social environment, as well as getting ready to collect observational data. It was over a period of prolonged learning and orientation.

*Videotaping* was attempted in the early stages, but was soon excluded because it was found to be very intrusive to other members in the OR, and because of the complicated medicolegal issues involved. In addition, one camera did not give enough coverage of the scene, but operating more than one camera was beyond the capacity of the current study (both in terms of costs and human resources).

## 4.3 Procedures in direct observation study

As concluded after the initial trials, it was decided *not* to do on-line recordings of observed activities. Rather, after each observation session, notes were made of the major events observed and anything that appeared to be interesting. Some segments of observed activities and events were documented in detail, but due to the lack of consistency in the recording process, these records were later found to be of little use.

### Cycles of observations

The general approach taken was to first identify apparently repetitive routines used by the subjects. Activities that did not follow these routines were then noticed, and previously established routines were either further divided and/or enriched. The process of establishing regularities is illustrated in Figure 4.1, which is reminiscent of Neisser's perceptual cycle (1976) shown in Figure 4.2 for comparison. The observation process, like Neisser's perceptual cycle, is an iteration of (1) forming hypotheses of recurring patterns, (2) making predictions, and (3) verifying those predictions, all in an overlapping manner. The findings are essentially the *final* results of the iteration.

Attention was paid to how problems were identified by the anaesthesiologists and how they were solved. In particular, the question asked at the beginning of this chapter, *i.e.*, "Were there any problems to be solved by the anaesthesiologist?" was the centre of the observation effort. This is not only an obvious question to ask when one starts to observe the expert's problem solving behaviour, but also as a way to test the common belief that experts have few problems to be solved, as indicated by Dreyfus and Dreyfus (1986): "An expert generally knows what to do based on mature and practiced understanding. When deeply involved in coping with his environment, he does not see problems in some detached way and work at solving them, nor does he worry about the future and devise plans"[4] (p. 30).

### A note on repeatedness

Behaviour in field conditions is contingent on the actual surrounding circumstances, which rarely recur in exact detail. On the other hand, however, it should also be noted that not all recurring patterns observed are interesting, not even those patterns that repeat in the majority of cases in anaesthesia. For example, consider the following action sequence:

- oxygenating the patient
- paralysing the patient
- intubating
- connecting breathing circuit

As one can see, the order of this sequence is *completely* determined by the task of anaesthesia (Cf. the procedural description in Section 3.2.2 starting page 39), and it would be almost impossible for an anaesthesiologist to act in any other order. More importantly, the sequence

[4] Or as more blatantly put by Stuart E. Dreyfus in a seminar, and I paraphrase, "the master plays chess by hand, not by brain."

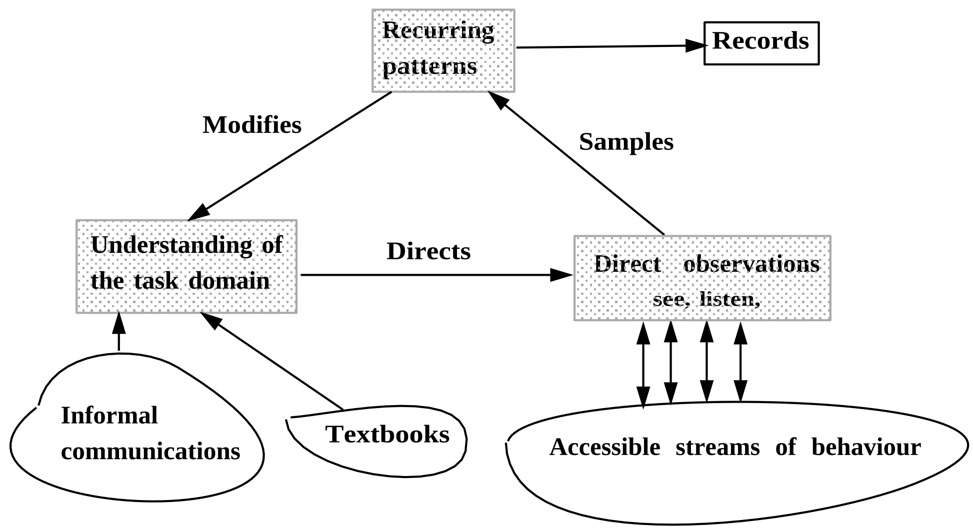



Figure 4.1: Conceptual chart for the process of obtaining behavioural patterns using direct observation method. Sources of information include not only the activities in the OR, but also textbooks and informal contact with the anaesthesiologists. The notes (record) of the direct observations were the intermediate products of an iterative process.

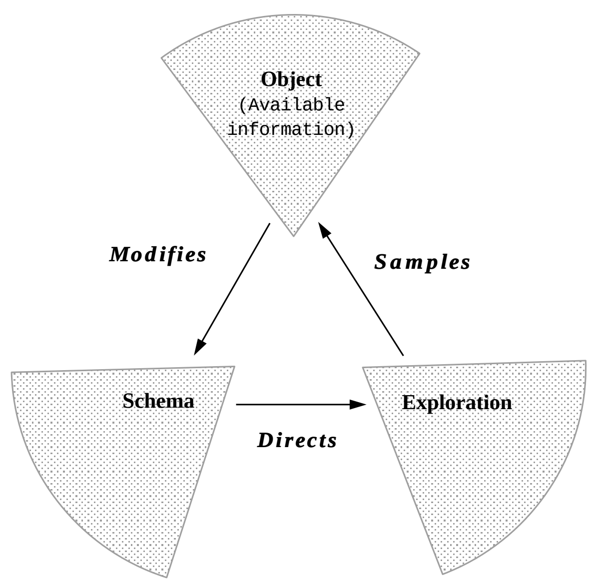



Figure 4.2: Neisser's perceptual cycle. Adapted from Neisser (1976, Fig. 2). The exploration of stimulus environment is directed by anticipation (schema), which is in turn modified by the information perceived. The three nodes in the perceptual cycle—exploration, object, and schema—correspond to the three nodes in the current study: direct observations, understanding of the task domain, and recurring patterns.

says little about the cognitive activities, and is definitely of no interest to domains outside anaesthesia.

Instead of seeking recurring patterns at spatial, temporal, or linguistic levels, this thesis looks at a higher level and addresses directly the cognitive constraints as opposed to just task constraints. At spatial-temporal-linguistic levels, activities observed can be variant and contingent. However, these varying activities can reveal a small set of strategies or habits that the subjects use to cope with the environment. The observed activities can also illustrate a few classes of situations that are cognitively demanding. What this thesis seeks is the strategies and problem solving situations that the observed activities have *repeatedly* demonstrated.

## 4.4 Results of the direct observation study

Despite the vast variations in the observed activities across cases and subjects, the direct observation study succeeded in establishing a phenomenological account of how problem solving situations arise and how they are being solved in the conduct of anaesthesia cases. This section first summarises the findings in a single framework, and then lists the four groups of findings in more detail.

### 4.4.1 Non-event-driven activities: A dominant feature

When studying problem solving behaviour, a natural and traditional approach is to concentrate on how the subject *responds* to the events in the environment. The focus is on what will be called the event → mental process → response (EPR) cycle, or how the subject *reacts* to events. With this approach, it is assumed that the subject starts a series of mental operations after perceiving a stimulus event. The mental operations then produce a response plan. Implicitly but clearly, it is also assumed that the subject's anticipation about the nature of the stimulus as well as the subsequent responses plays no role in the EPR cycle. This approach is illustrated in Figure 4.3. A more elaborate version is given by Wickens (1992, Fig. 1.3), which is meant to demonstrate various stages of mental operations mediating *between* an input stimulus and an output response.

In an event-driven work domain like anaesthesia, one would naturally expect that the dominant feature in the subject's activities is to respond to events such as instability in the patient's physiology or requests from the surgeon. The field study did notice activities of this nature. For example, in one case the surgeon unexpectedly punctured a major vessel (the pulmonary artery) and the patient's blood splashed onto the surgeon's mask. The anaesthesiologist had to respond promptly to the event, which was not anticipated but critical.

However, the field study also noticed that a significant portion of mental and physical activities were *not* reactive to *directly* perceived events in the OR. The problems being solved were apparently not associated with recent events, but with the subject's anticipation of future problem solving situations (Figure 4.4). In other words, these activities were *not* driven by immediate events in the environment.

The non-event driven activities found in the direct observation study can be aggregated into four groups of strategies:

- preparation of the *physical* workspace,
- preparation of the *mental* workspace,
- feedforward control of patient status, and
- task off-loading.

The *preparatory* behaviour in the first two categories can be represented by a single framework (Figure 4.5), which summarises eight areas of physical and mental activities in preparing for future responses. Note the contrast between Figure 4.3 and Figure 4.5.

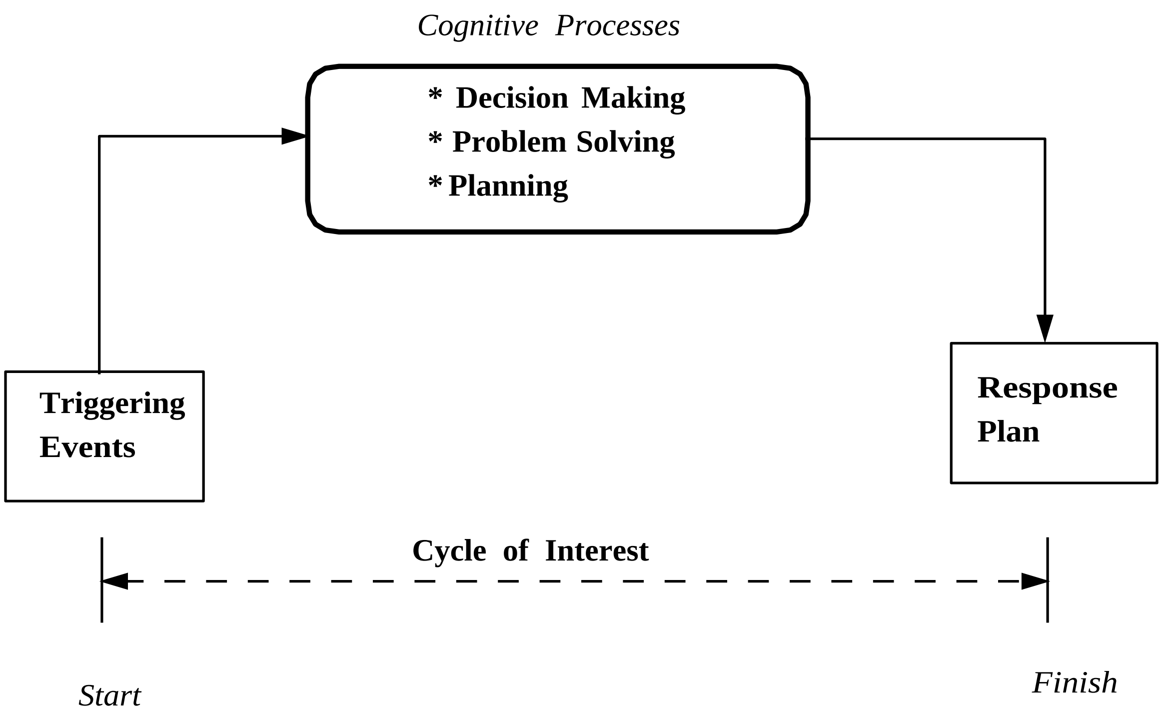



Figure 4.3: Traditional focus of study on human information processing: The event → mental process → response (EPR) cycle. Problem solving behaviour is studied as a one-shot activity.

### 4.4.2 Preparation of the "physical workspace"

Before the start of, and during, each anaesthetic case, a considerable portion of an anaesthesiologist's activities can be viewed as designing and tailoring the '*physical workspace*'—the work environment surrounding the anaesthesiologist—to facilitate his or her interactions with the patient and the equipment. Even though anaesthesiologists have formed their own, idiosyncratic routines for arranging the physical workspace, these routines converge in a number of aspects. The following is a list of observed patterns associated with this theme of preparing the physical workspace.

#### Preparing materials and access

See label P3 in Figure 4.5. Prior to the start of a case, anaesthesiologists tend to prepare drugs and equipment (*e.g.*, ETT) that are expected to be used. They gather tools and materials and arrange them for later use. Most of these prepared drugs are used in the induction phase of anaesthesia (usually about 4 or 5 syringes) and in emergencies (about 2 or 3 syringes). If the case is not the first of the day, this preparation is often done during the *preceding* case to shorten the overhead time between cases. The order in which syringes are prepared varies among different anaesthesiologists. However, most anaesthesiologists reported that they followed a more or less fixed sequence. For example, emergency drugs are prepared first, followed by induction drugs. Some anaesthesiologists even prepare drugs to be used at the end of a case. Devices such as the infusion pumps that take a long time to set up are also prepared in advance. Some materials are not directly available in the OR (especially those infrequently used drugs). Anaesthesiologists check the availability or order them to ensure later access.

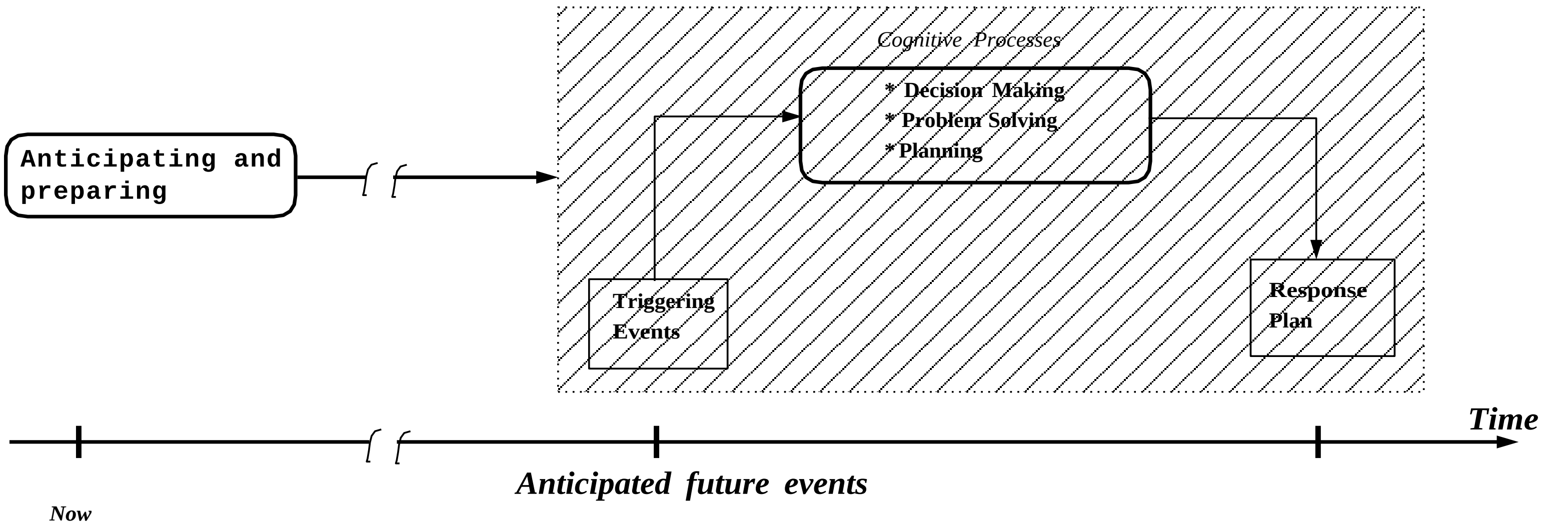



Figure 4.4: Anticipatory and preparatory activities in event-driven work domains. Note that anticipation and preparation do not in general eliminate the need for on-line mental processing. The impact of anticipation and preparation on the subsequent behaviour is a primary focus of the field study.

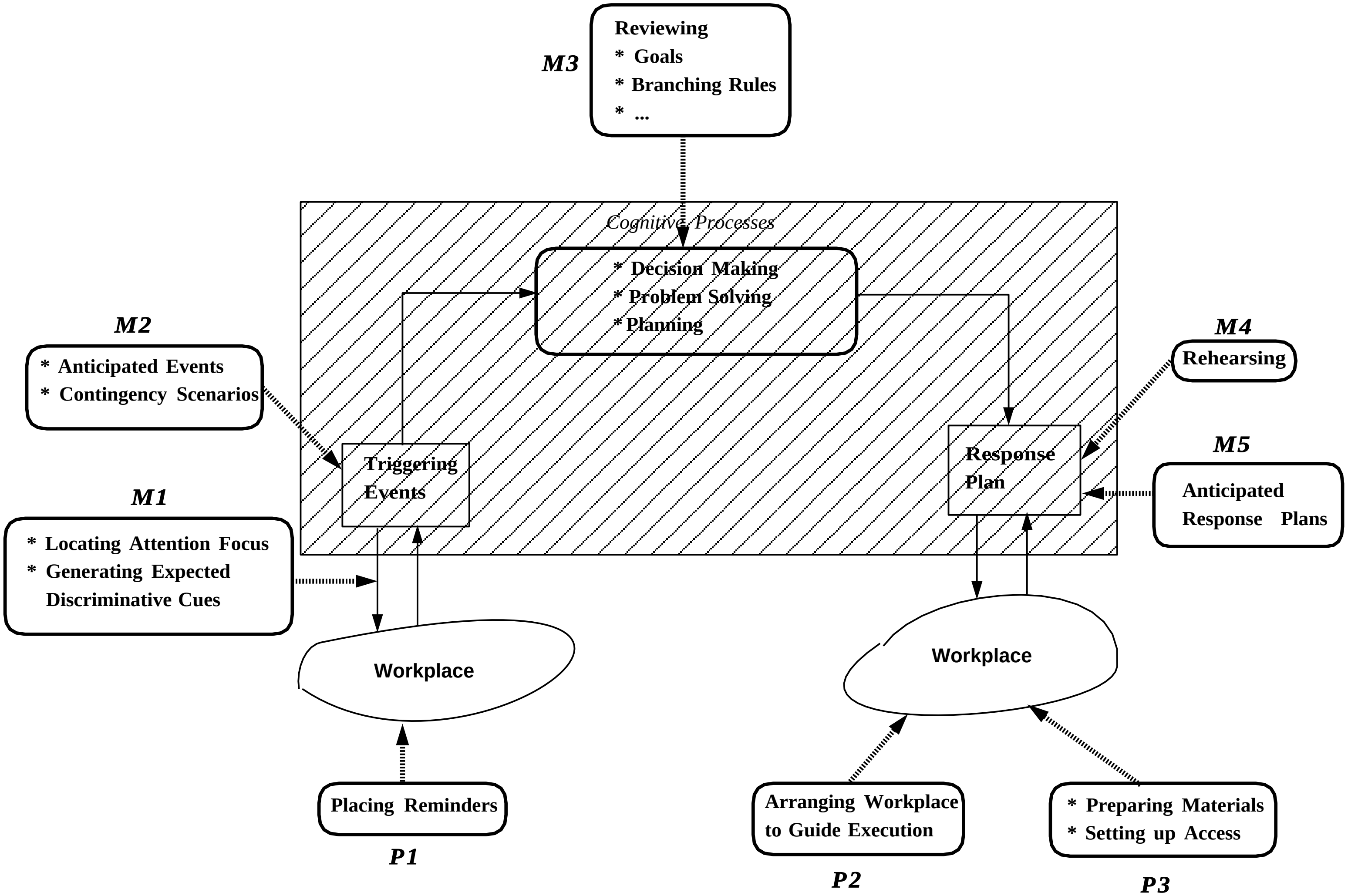



Figure 4.5: The preparatory framework for activities beyond the EPR cycle. Labels for physical and mental activities start with $P$ and $M$, respectively. See text for a discussion of the labels.

#### Laying out ampoules and syringes

See label P2 in Figure 4.5. The prepared syringes are laid out in a semi-structured fashion. Emergency syringes are usually placed separately from the induction syringes. Some anaesthesiologists even put emergency syringes in the upright position for easy identification and reducing the confusion caused by syringes on the drug cart. The induction syringes are often arranged in the order that they are to be used. It is not unusual to have more than eight syringes drawn up and laid out on the drug cart. Thus anaesthesiologists adopt various ways of making the identification process easy and fast. Labelling syringes, for example, has become an established step and is done by anaesthesiologists most of the time.[5] However, since the layout of syringes can be structured, and since the physical characteristics (*e.g.*, sizes) of syringes can give indications of what is in a syringe, anaesthesiologists do not always read the labels on syringes. In one case the syringe's needle was left in the ampoule and therefore the anaesthesiologist did not need to read the label on the syringe to identify it.

#### Making use of the physical workspace

See labels P1 and P2 in Figure 4.5. A glance over the physical workspace can provide anaesthesiologists with the information that they may not be able to remember reliably. Some of the anaesthesiologists' activities are centred around how to use this "displaying" characteristic of the physical workspace. Checking what remains in a syringe and which syringes are left over can tell one how much and which drugs have been given to the patient; reading the anaesthesia chart can remind one to check the patient's sedation level; empty infusion bags deliberately left on the infusion stand can tell one how many bags of fluid have been given to the patient without fearing errors or delays in log-keeping. These are all examples of using the physical workspace to keep track of what has been put in the "pipeline" to the patient and to facilitate the interpretation of monitoring signs. Anaesthesiologists continuously maintain the physical workspace by rearranging layout to reflect the changes that he or she has made to the patient and the equipment.

A more elaborate way of using the physical workspace was observed when the anaesthesiologist brought out drugs to be given to the patient and placed them on the drug cart. Thus, a scan of the drug cart can remind anaesthesiologists of what has been planned.

#### Making workplace "fail-safe"

See label P2 in Figure 4.5. Some ingenious ways of reducing errors by re-organising the workplace were observed. For example, in a case of total intravenous anaesthesia, to prevent the accidental delivery of vapourised anaesthetic agent, the anaesthesiologist taped all vaporisers, thus limiting a source of error—turning on the vaporiser inadvertently. In another case where the surgeon asked to stop ventilation for a while to operate on the lung, the anaesthesiologist held his hand on the knob and explained that in this way he would not forget to turn the ventilator back on. What is probably more interesting is the fact that when his hand feels sore, it should also be the time to turn the knob back on to oxygenate the patient. Considering various interruptions to the anaesthesiologist's attention, this trick essentially configures a "fail-safe" interface.

### 4.4.3 Preparation of the "mental workspace"

In contrast to the preparation of the physical workplace, preparation of solutions and contingency plans is not directly observable. Such mental preparation can be viewed as the

[5] Like many other things that anaesthesiologists do, even though labelling syringes has become a well accepted practice after the introduction of pre-printed, easy-to-apply stickers, there is no strict rule demanding the use of these labels.

establishment of a proper mental state, or a "*mental workspace*," for efficiency in execution of planned actions and responses to critical events.

### Pre-operative planning

See labels M1, M2, M3, and M5 in Figure 4.5. Receiving the assignment list marks the beginning of the anaesthesiologist's mental preparation. It was reported that, by seeing the name of the planned surgical procedures, anaesthesiologists had begun the preparation of the case; they entertain the critical points to be encountered and think about the important questions to be asked when reading the patient's medical records[6] and visiting the patient. After reading medical records and visiting the patient, many decisions have been made (such as the choice of the anaesthetic technique). The anaesthesiologist essentially plots the course of actions, including anticipated emergency situations. In the spontaneous reports, usually a few (less than three) key concerns (which are called 'anaesthetic considerations' by anaesthesiologists) were listed as primary problems either to be avoided, to be alleviated, to focus on, or to be solved in some particular way.

Contingency planning seems to be a part of routine preparation of anaesthesia. A good example is i.v. access. If there is a possibility of large blood loss, a large bore i.v. is planned and secured. Contingency planning was reported not just during the starting phase of anaesthesia, but often throughout the entire case. Anaesthesiologists reported that, before major interventions, the consequences of the intervention were mentally examined within the specific context. In the words of one anaesthesiologist, they try to "beware of the consequences."

### Priming and rehearsal

See label M4 in Figure 4.5. Rehearsal was reported before procedures that either have not been used for a while or need modifications. The rehearsal seems to be carried out with the help of visual or tactile contact with the equipment, the patient, etc. Missing information was obtained during the rehearsal (such as finding the exact body weight of the patient). Unfulfilled preconditions were prepared.

When a new surgical unit is used, anaesthesiologists usually make an attempt to familiarise themselves with the unit, the equipment settings, and the general layout (such as the location and the contents of drug cabinets).

### Anticipation of the patient status

See label M1 in Figure 4.5. For the majority of situations, anaesthesiologists seem to know when alarms will go off. This was inferred partly from the observation of the lack of attention paid to alarm signals. In other words, there are only a small number of cases where they do not anticipate that alarms will sound. Even in those situations, they rarely have to read messages from monitors for detailed information and suggestions. They seem to spend more time on how to silence the alarms than on finding out what may have caused them to go off.

Even though the OR has a very noisy background, either from auditory sources (*e.g.*, electrocautery and suction catheter), or from visual sources (darkened lighting during some surgical procedures, such as neurosurgery), anaesthesiologists can in general tune into the channel from which they are seeking information. A good example is looking for a breathing sign—coughing. The clinical sign of coughing is minimal under anaesthetised conditions, but anaesthesiologists have little trouble in detecting it when they are looking for the sign. As another example, picking up a trend from the monitors is not always easy due the fluctuations caused by various factors. The trend information is often obtained through

[6] Patients' records can be very extensive and can have several volumes.

combining anticipated trends with intervention given to the patient. In other words, displays are consulted more as a way of *confirming* trends rather than that of *detecting* trends.

In theory there are more than 30 parameters to be monitored about the patient. The anaesthesiologists are not sitting there being bombarded by information from those channels. Rather, they actively seek information, and organise their monitoring behaviour around concerns and anticipated trouble spots. For example, urine output is a slowly changing variable, and can be read only by bending down below the operating table. Ordinarily, it is only read infrequently. In a case where a urine problem is suspected, however, the urine output is consulted constantly.

**Local control and monitoring of patient status**

See label M1 and M3 in Figure 4.5. The task of controlling and monitoring patient status is relatively simple in the majority of situations. All the anaesthesiologist needs to do is adjust a couple of knobs, or repeat injection of the same drugs to control the fluctuation of physiological signs, mostly blood pressure, heart rate, capnograph, and ECG. Little indication is observed that complicated reasoning processes are involved in, for example, the setting of the control knobs or the choice of dosage and timing. One obvious question is: How can this be possible, given the large variations in patient conditions and types of surgeries?

During teaching sessions,[7] it was observed that local rules were generated to alleviate the burden of monitoring and controlling. These local rules were verbalised in forms like "when blood pressure rises to 150 $mmH_g$ I am going to check other parameters and give some $\beta$ blocker" or "now I just have to change the setting of the vaporiser to accommodate the surgical stimulation level." Local control rules, like the short-cuts in Rasmussen's (1976, see also Figure 2.2 in this thesis) decision ladder, reduce or eliminate complicated reasoning. Preparing or rehearsing local rules can also be viewed as a way of off-loading mental tasks and making a multi-tasking work environment more manageable.

### 4.4.4 Feedforward control

Feedback or error-nulling control is usually judged to be less satisfactory than feedforward control (Conant & Ashby, 1970). In the field study, it seems obvious that anaesthesiologists respond largely to anticipated future events. This is a finding similar to what other researchers have found about the behaviour of experienced subjects in other domains (*e.g.*, Bainbridge, 1974). A low blood pressure reading just before incision, for example, is treated very differently from how such a reading would be just after the surgery is over. Expected surgical events play a deciding role in the treatment of problematic trends. Anaesthesiologists pay close attention to what the surgeon is doing, from which they can anticipate future events and respond in a feedforward manner.

In the case of unfamiliar surgical procedures, they consult the surgeon directly or indirectly to acquire relevant information. For example, important future events, such as the timing of aorta unclamp and the expected finishing time, are not always clear to anaesthesiologists. However, the manner of asking information from the surgeon was found to be rarely explicit. Equally, the surgeon informed the anaesthesiologist of surgical events in similar implicit ways. For example, the surgeon may raise his or her voice when talking to the nurse to let the anaesthesiologist be aware of some critical information.

Due to uncertainties in the prediction of drug effects and in patient monitoring, feedforward control is never complete. Anaesthesiologists used the strategy of titration (*i.e.*, gradually adjusting dosage depending on the observed feedback) to deal with the uncertainty involved in predicting the physiological responses to interventions, either in terms of desired effects and undesired side-effects. The variation in patient conditions across popu-

[7] In a teaching session, the staff anaesthesiologist and the resident are doing the case jointly.

lations and surgical procedures suggests that each patient will have his or her own range of desired status and proper dosages. Anaesthesiologists make use of records from previous anaesthesia procedures to direct their dosage choice. Often anaesthesiologists wait and see to what values the patient settles down after the induction before knowing what the desired status is, with which future monitoring signals are to be compared. At the same time, local monitoring rules are formulated or detailed.

### 4.4.5 Off-loading

Anaesthesia is a process with highly unevenly distributed workload. During the maintenance phase of anaesthesia, very little physical action is observed and the anaesthesiologist is in a supervisory control mode. During induction and emergence[8] periods, on the other hand, both physical and mental workload is high. Anaesthesiologists have developed a number of ways of making use of the unevenness in workload by "off-loading" some of the tasks to the "cruise" time period (Cf. Cook *et al.*, 1991). Off-loading activities are not limited only to physical tasks, but to monitoring and decision tasks as well. Thinking through difficult manoeuvres before the start of a case can provide one with a small set of potentially troublesome situations along with carefully formulated solutions. Problem solving in this mode is subject to little time pressure, and thus factors that may not be considered in crisis situations can be examined. Even though not always explicitly devised, branching rules were reported to have developed to simplify the on-line decision making (Cf. Amalberti & Deblon, 1992).

### 4.4.6 Summary of direct observations

The phenomena listed above show a wide range of behaviour in anaesthesia practice. Yet they converge to the pattern that the anaesthesiologist behaves in an anticipatory and preparatory manner. In summary, these findings indicate the following:

1. Experience and training give anaesthesiologists both the ability and the tendency to anticipate the future. They also provide anaesthesiologists with the skill to identify and focus on key concerns efficiently and accurately.

2. Plans and decisions made by anaesthesiologists occur at different levels of detail, and are subject to frequent adjustments during the execution. The uncertainty involved in patient management makes feedback necessary in the execution of plans, such as in the form of titration.

3. Patient status is predominantly controlled in a feedforward manner.

4. Anaesthesiologists learn to use their physical environment to facilitate their mental activities. The workplace is used in at least three ways: (1) storing the intended plans (perspective memory), (2) storing interventions done to the patient (retrospective memory), and (3) providing an external visual or tactile representation for mental simulation and execution guidance.

5. To overcome bursts of high workload, anaesthesiologists offload tasks during low-load times.

These patterns outline some important features of anaesthesiologists' behaviour. They draw attention to the preparation phase of anaesthesia and the preparatory characteristics of behaviour. Their implications for further studies are examined in the following section.

[8] That is when the patient emerges from the anaesthetised state.

## 4.5 Implications for the following studies

The direct observation study described in this chapter provides an adequate orientation about the cognitive activities in anaesthesia management. The framework about the preparatory behaviour serves as a guidance for further studies that are to be described in the following chapters.

First of all, even though the majority of the cases are routine to experienced anaesthesiologists, there are still a number of problems to be solved. In particular, the successful eventual outcome of a case can not be used as the sign of an easy case. The majority of the cases finished without dramatic events. However, there were usually a number of incidents that, if not being coped with properly, could lead to serious accidents. Under the label of "a smooth anaesthesia," one can easily identify some episodes in most cases that have the potential of leading to a "rough ride." In addition, critical events during a case are not a reliable sign for triggering problem solving activities, as solutions to those events may have been prepared in advance.

Secondly, anticipation of future events is a critical component of many cognitive activities. This points to the importance of pre-operative activities, that is, those that take place before the anaesthesiologist arrives at the OR and before the start of the anaesthesia. Evidently important decisions are made before a case has even started. That means that thinking aloud protocols collected only during a case within the OR will *not* reflect directly those activities prior to the case.

Lastly, three categories of cognitive activities in the peri-operative period can be easily identified:

- keeping track of what has been given to the patient and of what has been planned to be done;
- substantiating and modifying general strategies and routines with respect to the specific case, and
- scheduling attention and activities in the multi-tasking environment.

The attention of the following studies focuses on the mental processes involved in carrying out these cognitive activities. These three categories of activities also partly answer the question of "what problems are being solved" by anaesthesiologists.

The following chapters in Part II will focus on the preparatory behaviour and its relationships to other observed cognitive activities. Mechanically recorded traces will be used to examine the behaviour at detailed levels.

# 5

# Protocol Study

> The difficulty in analyzing the actions of an animal does not arise from any lack of ways to do it but from an embarrassment of riches. We can describe an action as a sequence of muscle twitches, or as a sequence of movements of limbs and other parts, or as a sequence of goal-directed actions, or in even larger units.
>
> —*G. A. Miller,* et al.*, 1960/1986, p. 13*

## 5.1 Introduction

The direct observation study reported in the previous chapter serves to focus attention on preparatory and anticipatory behaviour. The proposed preparatory framework, shown in Figure 4.5, highlights eight areas of mental and physical activities that could shape problem solving situations in significant ways.

This chapter describes a study, referred to in this thesis as the *protocol study*, that focuses on these eight areas of preparatory activities by examining the observed behaviour through protocol analysis. The aims of the protocol study are to substantiate the major patterns of behaviour found in the direct observation study, to explore ways of analysing the protocols to study the anticipatory and preparatory behaviour, and to investigate the role of anticipation and preparation in the event-driven work domain.

## 5.2 Collecting protocol data

To obtain traces of events and activities in the OR, it was clear from the direct observation study that hand-written notes alone were not adequate. At the same time, the observation study also indicated the feasibility in the OR environment of using voice-recording devices and of deploying concurrent verbalisation or "thinking-aloud" techniques (although with only limited success, as described later). In the protocol study, two kinds of traces were obtained: observable events and physical activities that were recorded by hand-written notes, and audio-recordings of verbal and non-verbal sounds. These traces were *pooled* together to produce protocols for analysis.

Eight (8) recorded cases were selected for analysis. The total length of audio-recordings of these cases is about 30 hours. They consist of 880 episodes, and are from five (5) anaesthesiologists (two fourth-year residents, and three attending staff). The cases are listed in Table 5.1; detailed case descriptions are in Appendix D.

| *Surgery names* | *Subject* |
|---|---|
| Whipple procedure | JD (Staff) |
| Mitral valve replacement and aortic coronary bypasses | AL (Staff) |
| Valvular replacement | AL (Staff) |
| Bone marrow harvest | ML (Staff) |
| Lobectomy | NM (Resident) |
| Esophagoscopy | NM (Resident) |
| Cholecystectomy | JS (Resident) |
| Abdominal Aortoric Aneurysm | JS (Resident) |

Table 5.1: Case list in the protocol study. See Appendix D for detailed descriptions.

### 5.2.1 The setup

Subjects were selected from three kinds of background: senior residents (4th year) and staff anaesthesiologists with relatively limited (less than 10 years) to extensive (30 years) attending experience. The intention was to sample behaviour from subjects with various levels of experience. Request for consent for recording, explanation of the study, and instructions for verbal reports were given to the anaesthesiologist after he or she agreed to participate in the field study. See Appendices B and C for the introduction and the instructions given to the subjects prior to cases.

Once a subject was chosen, it was left to him or her to decide which case(s) to observe and record. The subject was given the general guideline that the case should not be too routine, or excessively complicated, or too short (less than 30 minutes), or too long (longer than 7 hours). These preferences were to limit extreme cases but still allowed the majority of cases to be studied. It turned out that limitations in case selections were mostly for logistical reasons (*e.g.*, interference with on-call schedule, too close to vacations, multiple duties, etc.).

Audio-recording was done through a wireless microphone to eliminate extra wires in the already cluttered OR environment. An audio tape recorder and the receiver (both battery powered) were placed in a corner or hidden under furniture. The microphone was clipped on the subject's OR gown; the transmitter was placed in a pocket in the gown. The microphone was usually *not* concealed,[1] although the intention was to make the recording devices as unintrusive as possible. The anaesthesiologist had the option of switching the microphone to standby when she or he did not wish to be recorded, such as during breaks or private conversations not relevant to the case. During the protocol study, however, the microphone was not turned off by the subjects for these or any other reasons.

### 5.2.2 Generating protocols

The procedure used to generate protocols is shown in Figure 5.1, and is described below in the order of recording.

#### Pre-operative interview

The pre-operative, or "pre-op," interview was carried out to obtain information about how the subject prepared for the case. The interview took place *after* the anaesthesiologist had already seen the patient. The anaesthesiologist was asked to first give an overview

[1] At least one of the nurses in every case noticed the microphone. Consequently, nurses often asked the anaesthesiologist to explain what the microphone was for.

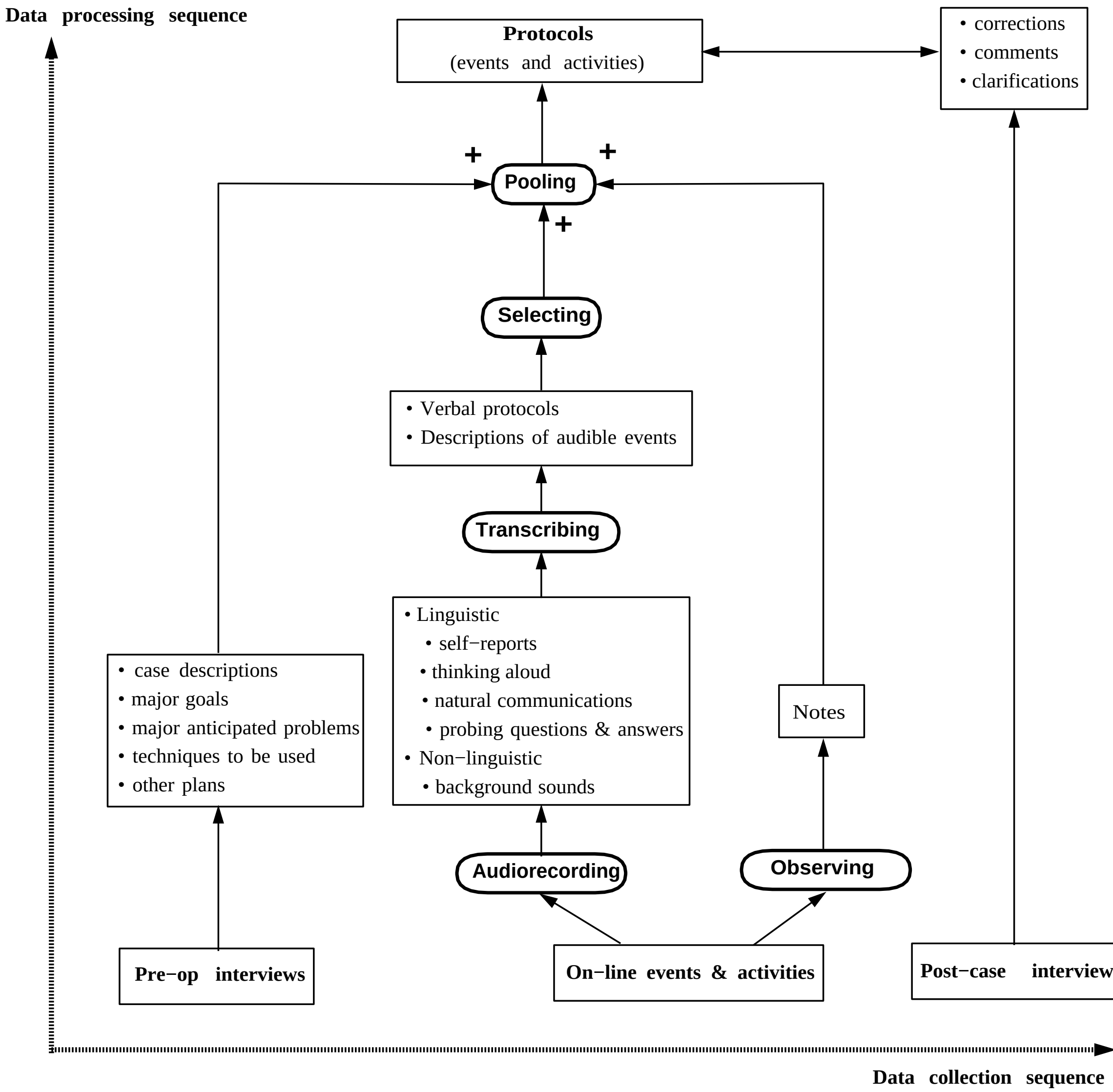



Figure 5.1: Process of generating protocols. Raw data were collected from the interview before the surgery, the on-line audio-recordings during the surgery in the OR, and the post-case interview, which was done *after* the on-line recordings were transcribed and were pooled with the pre-op interview and hand-written notes made during the surgery. Note that each case was processed individually.

Specific questions:

- Give me a short description of the case as if you were to present it to your peers, including significant findings and outstanding surgical procedures.
- What are the major concerns that *have actually gone* through your mind?
- What are those items that you think are unique to this case?
- What have you planned for the case beyond the general routines?
- What are the specific actions that you have listed for yourself to do prior, during, and after the case?

General questions:

- What are the concerns that you might have asked a resident to consider?
- What do you expect a resident to have prepared up to this point?
- What is the expected surgical course?

Table 5.2: Questionnaire for the pre-operative interview. General questions are asked not for the purpose of *generating* protocols, but for the purpose of *understanding* the protocols. Consult Appendix C for details.

of the case (including the patient's conditions and the expected surgical procedures), and then to report his or her activities regarding the case, up to the time of the interview. See Table 5.2 for the questionnaire used. The questionnaire was constructed based on the experience gained in the direct observation study. It reflects the emphasis on mental and physical activities associated with anticipation and preparation. Although the questionnaire may appear to be too suggestive (*i.e.*, biasing the reports in favour of the field study), it essentially contains the same kinds of questions that an anaesthesiologist "instructor" would ask to a resident about case preparation. In describing a case to a colleague, furthermore, an anaesthesiologist usually does so by answering most of these questions.

The information obtained from the pre-op interview usually fell into the following categories:

- the case overview,
- particular problems and difficulties that were anticipated at the time,
- special techniques that were considered,
- special material and preparation needs, and
- a few troublesome scenarios and critical points during the surgery.

The interview was transcribed, summarised, and then presented to the subject *during* the case for correction and clarification.

### Peri-operative recordings

Traces of events and activities during the case were recorded by two means: audiotaping and hand-written notes. Through observations, major events, especially those that were expected to be difficult or impossible to detect from tape recordings, were written down with timestamps. Data recorded by hand-written notes consisted of patient status, drug names, laboratory test results, as well as major activities (*e.g.*, intubation, incision, and so on).

Audio-recordings captured both linguistic and non-linguistic sounds. Linguistic information included four kinds of verbal data:

- self reports—reports that were given to the observer without specific requests from the observer. They occurred when the subject *talked to the observer without being asked or prompted.*
- naturally occurring communications among the team members in the OR. They occurred when the subject and other team members *talked to each other.*

- What are the expected problems, both in short term and long term?
- What is your current assessment of the patient status?
- Are there any specific scenarios that you are trying to, or you have been trying to, avoid?
- Do you have any specific goals/patient status that you are trying to achieve?
- How would you summarise the case so far?
- Suppose you want to leave now and give the job to a reliever with the same experience, what would you tell him/her?

Table 5.3: Sample questions for concurrent probing in the peri-operative phase. These questions were posed to the anaesthesiologist in an opportunistic, instead of planned and systematic, manner. Consult Appendix C for detail.

- "thinking aloud"—verbalisation of actions and mental activities. It occurred when the subject *talked to him or herself*.
- concurrent probings that were initiated by the observer (see Table 5.3 for some of the questions used). They occurred when the subject *was asked or prompted*.

Non-linguistic information consisted of those audible background sounds, such as alarms and vacuum suctioning.

### Preliminary processing of trace data

Audio-recordings and hand-written notes taken during the operation constitute the *trace data* about what had happened. The first step was to convert these trace data into transcripts.

Recorded tapes were transcribed either by the observer or by professional transcriptionists. (In the latter case the observer went over the tape again to correct transcription errors.) By matching timestamps, hand-written notes were merged into the transcripts. The tapes were then reviewed once again to identify speakers and to add other cues present in the tape, such as locations and activities of the subject (*e.g.*, the subject opened the refrigerator to pick up blood units). The transcripts were then "*scriptised*" by describing scenes, speakers and conversation partners. The process is called *scriptisation* because the resulting form is quite like the scripts for a screenplay. See Appendix E for an example of the scriptised transcripts. Scriptised transcripts contain four types of data: (1) *roles*—who is talking and to whom, (2) *linguistic actions*—what was being said, (3) *physical actions*—what was done, and (4) *scene*—patient status and surgical progress. Note that the transcripts contain not only verbal protocols, but also descriptions of circumstances and physical activities. The scriptised transcripts will be referred to as *protocols* or *protocol data*, and are considered as the *raw data* for analysis. During the scriptisation process, all confidential information (such as names, room references, and dates) was deleted. In essence, the protocols were a reconstruction of the actual sequence of activities, but were also inevitably the result of subjective selection and filtering. For example, protocols judged irrelevant to the task of anaesthesia were thrown away or abbreviated.

### Post-case interview

After the protocols were reviewed and the areas that deserved further probing were marked, an interview was arranged with the subject. Even though efforts were made to shorten the time needed to process the transcripts before the interview, there was usually a lag of two to seven days between the time of recording and the time of the interview. The lengthy time needed for transcribing and processing recorded tapes and producing the protocols was largely responsible for the delay between the completion of a case and the post-case interview. Logistical concerns of the subject were also a contributing factor.

As mentioned earlier, the primary purposes of the post-case interviews were to fill in the missing parts in the trancripts, and to correct suspected recording errors and "slips of the tongue." The subject was presented with the protocols and asked to comment on the major episodes in chronological order. Part of the results from the post-case interview were integrated directly into the protocol data. Other comments were used as supporting materials for the protocol analysis.

### 5.2.3 Limitations of verbalisation in work settings

Soon after the recordings started, it was clear that the thinking-aloud method in naturalistic settings with other personnel present was not as effective as had been hoped for in obtaining data about mental activities. Other means (*e.g.*, concurrent probing) had to be used in conjunction to obtain traces of the cognitive processes.

The first problem was the barriers to verbalisation posed by the social environment in the OR. For example, anaesthesiologists were found unwilling to report hypothesised problems while in the OR, perhaps to avoid being overheard by nurses and surgeons. Before the patient was brought to unconsciousness, the anaesthesiologist definitely did not want to alarm the patient by verbalising problems. As another example, although the anaesthesiologist had explained to other members of the OR that he or she was not insanely talking to himself or herself, verbalising in front of others was an awkward thing to do.

The second problem was the lapses in the verbalisation. There were often long periods during which anaesthesiologists were busy doing things and did not verbalise. Because of the nature of the work domain, verbalisation was frequently interrupted by the events in the OR and by communications with other team members.

The third problem with on-line verbalisation was the workload imposed onto the subject. Maintaining verbalisation throughout a case was impractical due to the sheer length of most cases (a medium length in the recorded cases lasted over two hours, excluding the preparation time). Verbalisation taxed the subjects' cognitive resources considerably. After an hour or so, the subject simply did not verbalise as much, if at all.

These problems offset the assumed advantage of thinking aloud protocols over other forms of verbal protocols (see Ericsson & Simon, 1984).

The problems with the thinking-aloud method were compensated partly by three other kinds of verbal data: concurrent probing questions, self-reports, and post-case retrospective reports. *Probing questions* were aimed at the retrospective reports of what had just happened and what the anaesthesiologist expected to happen. Clearly these probing questions could, judged by the data model by Ericsson and Simon (1984), yield more reliable information than questionnaires at the end of the case. This is so because the events and activities to be recalled had just occurred, and the OR environment provided a strong support for the subject to give retrospective accounts of what had just happened. However, concurrent probing could conceivably fail to ask questions that in retrospect should have been asked. Missing information about mental activities may not have been detected until after the verbal transcripts were processed, days after the case had been completed.[2]

*Self-reports* were found to be an excellent source of information on the mental activities of the subject. These reports were given on many occasions, usually in the form of explaining reasons for actions, assessment, expectation, intentions, and future plans. It was often the case that self-reports were mixed with thinking-aloud verbalisations. Apart from their role of compensating the limitations of the thinking aloud method, self-reports also provided guidance for understanding the recorded events and activities.

*Post-case retrospective reports* were obtained after the transcripts had been analysed

[2] In general it took 1:15 ratio to transcribe the recorded tape and merge information from other sources into the transcripts. A case of medium length can easily last three hours, which means that it would take 45 hours on the average to transcribe and get back to the anaesthesiologist.

preliminarily, and thus areas of interest could be targeted effectively. The objective was to meet the subject as soon as possible to reduce the difficulties for the subject in recall of events, mental states, and activities.[3] One limitation in achieving this objective was the time available for post-case interviews, since it was very difficult to arrange interviews (of adequate length) with anaesthesiologists. Another limitation was the time needed to process the transcripts, as pointed out in the footnote 2.

### 5.2.4 An overview of the protocol data

Even though the focus of the research is on mental activities in problem solving, a number of other factors influenced the data obtained. At the surface level, the micro-social environment in the OR, verbalisation processes, and the observer's probing questions all had a direct impact on what anaesthesiologists said and thus on the protocols. At a deeper level, the particular surgical procedure and the patient's physiological status played influential roles in the kinds of problems which occurred from moment to moment. Therefore, abstraction was necessary to obtain general patterns about mental activities from specific physical or speech acts in the data. Usually, the transcripts do *not* give sufficient information for the observer to determine the exact underlying mental activities. In many situations, verbal protocols from thinking aloud essentially were self-descriptions of what the anaethesiologist was doing, instead of how he or she had arrived at the choice of actions, or if there was a choice at all. The majority of the protocols were not about the reasoning processes, but the *results* of those processes—observations, intentions, actions, etc. (Cf. Rasmussen, 1976). Even though on some occasions justifications of actions were given, it was questionable whether or not those justifications could be taken literally. Thus it requires the analyst to make inference on the underlying mental activities, and there is no logical way for one to "prove" that such inferences are valid from the field data (Cf. Bainbridge, 1979).

The following is an overview of the obtained protocols that shows the contents of the protocol data.

#### Natural communications

This category of protocols reflects the natural communications among the people in the OR that were *not induced* as a result of the field study.

*Information request.* Anaesthesiologists asking for data:

Ex: • When is the surgery going to finish?

Ex: • What kind of tape is the patient allergic to?

*Being informed.* Anaesthesiologists being informed by other members of the OR team:

Ex: • There will be both flexible and rigid bronchoscopy.

*Instruction to the patient.* Instructing the patient:

Ex: • Make a fist, please.

*Informing the patient.* Explaining procedures to the patient:

Ex: • I am going to put a probe on your finger.

*Checking the patient.* Asking questions to the patient, either to confirm or to check the patient's status:

Ex: • Did you get a shot or anything this morning?

*Instructions to other team members.* Orders given to nurses, the resident, or the perfusionist:

Ex: • Would you tie this for me?

Ex: • You'd better give her some pancuronium.

[3] Anaesthesiologists could have done several cases in a row in a day, and it is reasonable to assume that they could mix up events from one case with those from others.

### Reports to the observer or thinking-aloud

Either in the form of thinking-aloud, or brief, unsolicited reports, the subject told the observer directly or indirectly about his or her mental or physical activities.

*Action report.* Describing actions being taken:

Ex: • I am giving another dose of morphine.

Ex: • I am checking the dosage the patient took in the last anaesthetic.

*Explanations.* Giving reasons for actions:

Ex: • I am doing that because I think the patient is a little light.

*Assessment of the patient's status.* Describing the status of the patient:

Ex: • He is getting sleepier and sleepier.

Ex: • She's got almost a litre of fluid so I don't think she's hypovolaemic.

*Verbalised observations.* Reporting observations of the workplace:

Ex: • So this bag is empty.

Ex: • It's amazing that the CVP goes right up when you elevate the table.

*Assessment of action results.* Describing the assessment of action results:

Ex: • Three ml may not be enough for an adequate seal.

*Intended actions.* Verbalisation of intention to act:

Ex: • I did not draw any pancuronium so that's the next thing that I want to do.

*Verbalised reasoning.* The anaesthesiologist reasoning aloud:

Ex: • Her pressure is about 87 here, about 100 and ...I'm going to give her a little of epinephrine and pump her pressure up to the region that I am happy with.

*Prediction.* The anaesthesiologist predicting future events:

Ex: • She's probably going to put up a lot of pee.

### Concurrent probing questions and anwers

When the subject appeared to be available for questions, the observer asked questions with regard to actions and events in the immediate past.

*Explanations of past actions.* Answering questions about actions taken:

Ex: • It was down low enough that is tolerable, but I had felt more comfortable when it was higher. Some people would say that it was more to treat me to reduce my anxiety than to treat the patient. But I don't want her blood pressure to drop below 100.

Ex: • I just wanted to see what it was, as it looks kind of strange.

### Pre-operative interviews

During the pre-op interview the subject described the case, as well as decisions regarding the conduct of the case.

*Pre-op observations.* The subject describing his or her observations when visiting the patient and reading the medical records:

Ex: • The patient is frail and does not really need much sux.

Ex: • This patient was hypertensive on the floor.

*Troublesome findings.* The subject listing problems about the case:

Ex: • Massive bleeding is a real possibility here.

*Plans.* The subject describing plans for the case:

Ex: • Maintain deep muscle relaxation.

Ex: • I am not going to push the use of vapour.

Ex: • I plan to use all means to block the response down.

*Contingency responses.* Responses prepared for anticipated critical situations :
Ex: • In case that blood pressure is hard to control, I'll start the nitroglycerin.

### Hand-written notes about observed actions and events

Hand-written notes that were pooled into the transcripts of audio-tapes captured both inaudible activities and events, as well as scenes that helped the interpretation of the verbal protocols.

*Physical activities.* Actions directly observable that may or may not be detectable in the audio-recordings:
Ex: • The anaesthesiologist is fixing the new BP cuff.
Ex: • The surgeon is cannulating the aorta.

*Patient status information.* Laboratory test results or monitor readings:
Ex: • CVP = 18 mm $H_2O$.

* * *

The above overview shows that the data acquired reflect an amazingly large amount of information on the task in anaesthesiology. It is well beyond the scope of this thesis to exploit all aspects in the protocol data. What is of interest in this thesis are those data related to how problem solving situations arise and to the strategies used by the subjects in solving them. In particular, the focus is on those activities that are associated with anticipatory and preparatory behaviour.

The protocol data also highlight the issues discussed in Chapters 2 and 4 about the level of analysis. The task complexity and the dynamic work environment have essentially eliminated the possibility of analysing the protocols at a sequential, syntactic level that aims at an explicit model (Carroll & Johnson, 1990, pp. 77–83). The protocols should be treated exclusively as a basis for understanding streams of behaviour, whose structure and organisations are the focus of attention, instead of sequential patterns at a linguistic level. Just as Hollnagel *et al.* (1981) characterised the raw data from the field, the protocol data "may be regarded as *performance fragments*, in the sense that they do not provide a coherent description of the performance, but rather the necessary building blocks or fragments for such a description" (p. 10, original emphasis).

## 5.3 Analysing protocol data

As expected, the on-line verbal protocols generated do not give direct access to the subject's cognitive processes. Rather, they provide *indications* to the underlying mental activities. The majority of the protocols were not about the reasoning processes themselves, but the results of these processes—the subject's observations, intentions, and actions (Cf. Rasmussen, 1976).

Given the nature of the protocol data obtained, the analysis stresses the semantics and understanding of the *flow of events and activities*. Effort was spent on studying the episodes in each case in detail. Various explanations were put forward to account for the observed behaviour. Whenever a fresh new perspective was used, earlier explanations were often modified or even rejected after the protocols were examined again.[4] This is very similar to what Rasmussen and Jensen (1973) have reported about their analysis of protocol data.

The method of protocol analysis was devised roughly according to the scheme proposed by Hollnagel *et al.* (1981, Fig. 2). The protocol data were analysed at three different levels of detail:

[4] Allowing repeated examination and analysis is certainly a significant advantage that the protocol study has over the direct observation study. This advantage justified the added effort required by the protocol study.

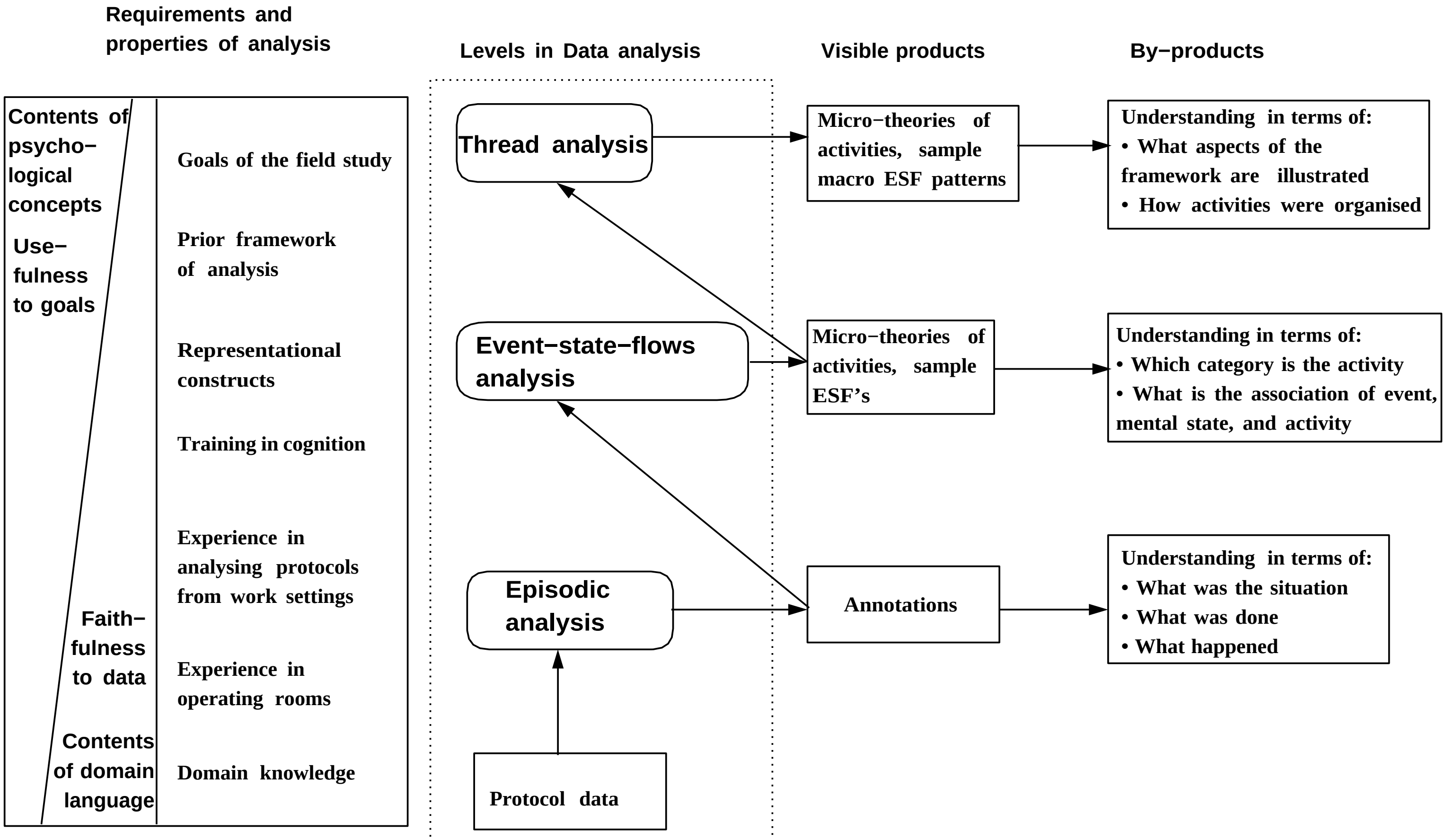



Figure 5.2: Scheme of protocol analysis. The protocols were analysed at three different levels, each producing its own products and an understanding of the recorded activities at that level. At the same time, each level of analysis imposed requirements, different from other levels, on the analyst.

- Episodic analysis
- Event-state flow (ESF) analysis
- Thread analysis

The method is shown in Figure 5.2. The three steps in the figure are described in detail below. Note that even though each level of analysis is a pre-condition for the subsequent levels, it provides results about the subject's behaviour at its own level of detail.

### 5.3.1 Level 1: Episodic analysis

*Episodic analysis* examines the protocols at a detailed, semantic level. The nature of analysis falls somewhere between exploratary analysis and content analysis as described by Carroll and Johnson (1990). Protocols were segmented into episodes, each of which was a relatively self-contained event/activity description. Efforts were placed on *understanding* the events and activities in each episode. Three basic questions were asked:

- *what* had happened,
- *what* had been done, and
- *what* was the situation.

Annotations were made to those episodes that contained indications of interesting mental activities, in particular those that were related to anticipatory behaviour and the eight areas identified by the preparatory framework (see Chapter 4). The protocol data were condensed and structured during the episodic analysis, and annotational notes were added. Events and activities were identified, and information hidden in the protocols with regard to specific situations (*e.g.*, patient status, the phase of the operation) was made explicit. Appendices G through L provide examples of how protocols were segmented into episodes and how notes were inserted. The protocols in Appendix E and the annotated version in Appendix I are from the same case and thus provide a comparison for the reader.

In short, the episodic analysis is a process of filtering out certain contents and details, cutting the continuum of protocol data into organised units, and adding annotational notes. This process was clearly influenced by both the investigator's familarity with the anaesthesiology domain and the prior goals of the field study. Needless to say, the process of the episodic analysis relies on a deep understanding of the events and activities within their domain context.

### 5.3.2 Level 2: Event-state flow (ESF) analysis

Based on the results from the episodic analysis of each episode and the whole case, *identification* and *categorisation* of mental activities were then carried out, to obtain the first level of abstraction from the protocols. The mental activities are either identified directly with the help of verbalisation and self-reports, or inferred based on the understanding of each episode.

The categorisation was an iterative process. Activities were first tentatively categorised and accumulated. The categorisation scheme was then gradually adjusted to accommodate new categories of activities. Part of the results of the identification and categorisation process were coded by simple diagrams as abstract representations of the activity, the mental states, and their interplays with the environmental events. These diagrams, referred to as *event-state flows* or ESFs, link situations, environmental events, and the subject's mental states and activities. ESFs represent the results of understanding the protocols through hypothesising causal links and information processing paths. See examples in Appendices G to L. Section 5.4.5 gives a description of the diagrams used. Previous researchers (*e.g.*, Bainbridge, 1974; Woods, 1984; Pew *et al.*, 1981) have used charts that are, in principle, very similar to ESFs to demonstrate cognitive issues. The difference between the ESF and the flow diagrams used by previous researchers is that ESF places emphasis on the operations carried out by the subject and the effects of those operations on the subject's mental workspace.

In the studies done by Newell and Simon (1972), the collected protocols were essentially completely coded and accounted for. The coding was based on the complete representation of the problem space. The problem space for the anaesthesiologist is much more complex than those in solving mathematical puzzles. The protocols collected in the present field study contain information about activities beyond the immediate interest of this thesis. A considerable portion of the episodes in a case were retained for the sake of context continuity, but the activities of this nature were not coded or annotated.

At the level of ESF analysis, the scope of study was largely limited to *within* each individual episode, even though references were often made to other episode(s). One can view these diagrams as micro-"theories" about the recorded activities. No attempts were made in the current field study to employ other analysts to study and to interpret the protocols for comparison.

### 5.3.3 Level 3: Thread analysis

A review of the annotated protocols would quickly make it clear that an analysis ending at the level of episodes is not adequate. Cross references among episodes are inevitable if one is to follow a thread of activities. The next level of protocol analysis was to examine the protocols at a larger scope explicitly based on *threads*, not episodes. The focus of the thread analysis is on the structural properties in the observed activities, that is, how activities related to each other.

After repeated examinations of the protocols at the first two levels of analysis, major threads of activities in a case usually became clear. Based on threads, rather than episodes, the thread analysis extends the ESF coding scheme and uses it to represent the interaction among the mental workspace, physical workspace, events and activities, and how the anaesthesiologists *actively* organise their behaviour to cope with the task demands.

## 5.4 Results of the protocol analysis

The episodic analysis is basically a process of understanding what the subject was doing over the course of a case, whereas the ESF analysis is to elicit and group the findings in the episodic analysis and to describe them in a cognitive language (*e.g.*, goals, expectations, cues, concerns, etc.). This section first describes the findings in detail, along with the coding scheme that captures the gist of the first two levels of analysis. It then describes the results from the thread analysis about those activities that beg an analysis *across* episodes.

Through examining the flow of events and activities, a number of patterns of behaviour were identified. These patterns not only strengthen the central findings in the direct observation study about the anticipatory and preparatory behaviour, they also provide instances of anticipatory and preparatory behaviour that enrich the understanding of how the subjects, as proficient problem solvers, organise their efforts to deal with the dynamic and complex task environment. These patterns were categorised and coded in ESF to extract underlying cognitive issues that illustrate how problem solving situations occur.

The results of the analysis contain two kinds of findings: *general* findings on the anticipatory and preparatory behaviour, and the *specific* patterns of behaviour that illustrate how the subjects respond to the task environment in a anticipatory and preparatory fashion. All these patterns reveal some underlying cognitive issues associated with the preparatory behaviour. The eight areas of activities in the proposed preparatory framework in Chapter 4 provide the guidance for all analyses.

### 5.4.1 List of concerns in mental workspace

At the beginning of each case, the anaesthesiologist identifies a list of *concerns* after examining the patient and reading the medical records. These concerns fit in one of the following forms:

- general problems in the patient's status (*e.g.*, the patient is old and weak)

- expected difficulties in executing procedures due to the patient's condition (*e.g.*, the patient has a short neck and is difficult to intubate)
- tasks that are special to the case (*e.g.*, the patient needs steroids)
- expected or likely troublesome scenarios (*e.g.*, there may be massive bleeding)
- unusual surgical procedures (*e.g.*, the surgeon will experiment with laparoscopy)

One can view such a concern as a "tripwire," or a "warning flag," that the anaesthesiologist "places" in the mental workspace. During the course of the case, some of the concerns are eliminated or alleviated, and new ones are added.

The functional roles of the concern list are many. It helps the anaesthesiologist to pay attention to precursors of troubles, to avoid situations where no solutions or effective solutions are available, and to be ready for problems, both mentally and physically. It enables the anaesthesiologist to resolve goal conflicts without having to do so under great time pressures; it allows the anaesthesiologist to allocate attention effectively during the case. The process of formulating the concern list itself also primes the anaesthesiologist to potential problems so that he or she can react more quickly than he or she otherwise could. More discussion on the functional roles of maintaining a concern list appears in Part III.

The following are the specific patterns of activities associated with the concern list in the mental workspace. In terms of the preparatory framework (Figure 4.5), these activities fall into areas M1, M2, and M3. Episodes referred to can be found in the appendices and will be labelled as **`appendix number:episode number`**. Occasionally page numbers are provided to encourage the reader to read the protocols. The reader is especially encouraged to read Appendix F to get an orientation to the protocol data in the appendices.

1 *Stacking a concern into the concern list.* Mostly during the pre-op interview, the anaesthesiologist reported concerns to the observer in one of the forms listed earlier. Even though the observer did not have access to the time when a concern was formulated or how a concern was alerted, it is assumed that the operation of stacking a concern *must have been done*. Examples of the stacking operation can be found in pre-op interviews in Appendices H to L.

   Another situation in which concerns are stacked into the concern list is when executing an action. The execution of an action often makes the anaesthesiologist think about undesired side effects, as shown, for example, in the retrospective report in the Episode I:Lob-29. In that episode, the intubation was expected to drive up the blood pressure, whereas the patient was hypertensive and the anaesthesiologist was worried about a high blood pressure reading.

2 *Activating a concern.* This was detected when the anaesthesiologist reported that a concern stacked earlier was activated and was a guidance for actions. The protocols do not show a large number of occasions in which a concern had an observable impact on specific actions, however. For example, difficult i.v. access is a concern for many cases. One can hypothesise that such a concern will lead to more focused attention during cannulating the vein. But that effect is difficult to detect. Episodes G:Wp-24 and I:Lob-13 are two instances where activation of a concern is clearly shown in the protocol data.

3 *Reviewing a concern in light of a specific situation.* When monitoring the patient or rehearsing actions, the anaesthesiologist reviewed a concern stacked earlier in the context of the specific task to be performed in the specific situation. See Episodes H:Val-11 and I:Lob-17.

4 *Other operations on the concern list.* These operations include removal and alleviation. During the course of a case, new information came in and allowed the anaesthesiologist to rethink the concerns that he or she had formulated. See examples in Episodes H:Val-116 and I:Lob-33.

### 5.4.2 Utilising the physical workspace

Throughout each case, the anaesthesiologist constantly modifies and reconfigures the physical workspace. Scanning the surrounding environment not only gives the anaesthesiologist information about the progress of the surgery, but it also functions as a way of reminding him or her what needs to be done. Audio-recordings only gave indirect reference to the scanning process, but post-case interviews and hand-written notes do provide leads to such activities.

Using the "displaying" nature of the physical workspace, the anaesthesiologist places cues for actions in the workspace. This is the case in particular for those actions that are not an *integral* part of anaesthesia, such as injections of antibiotics and steroids. The anaesthetic chart—a log book for keeping records of the patient's status and drug usage—is a special artifact in the physical workspace. Reading the chart often triggers the anaesthesiologist to check slowly-changing parameters of the patient, such as the relaxation level, the fluid balance, and the body temperature.

The following is a list of activities that illustrate how the anaesthesiologists utilised the displaying properties of the physical workspace, and fall into areas P1, P2, and P3 in Figure 4.5. Again, episodes are referred to as `appendix number:episode number` and can be found in the appendices.

1 *Placing cues in the physical workspace.* There are many ways in which the anaesthesiologist could arrange the surroundings in support of his or her memory. Arranging syringes on the drug cart is probably the most frequently used way. However, it is difficult to capture such activities in the protocol data. What can be easily found in the protocols are those activities that are for non-routine drug usage. See for example Episodes H:Val-24 and K:By-8. In both these episodes, the anaesthesiologist placed the ampoule boxes on the drug cart to remind himself to prepare and possibly to give the drugs.

2 *Scanning for action cues in the physical workspace.* In doing this, the anaesthesiologist "reads" the environment for answers to the question: "what should I do next?" Cues placed in the physical workspace remind the anaesthesiologist of the tasks to be done. See Episode H:Val-82.

3 *Reconfiguring the physical workspace.* While rehearsing actions to be executed, the anaesthesiologist reviews the workspace and prepares it, either by rearranging the layout, bringing out needed materials, or setting up access. See Episodes G:Wp-21, H:Val-21, and I:Lob-20.

4 *Checking the action "pipeline" in the physical workspace.* Over the course of a case, the anaesthesiologist has to carry out a great number of actions. Thus checking out what actions have been done and what have not been done could be a memory burden for the anaesthesiologist. Reading charts and scanning the physical workspace are two other ways of dealing with the memory burden. See Episodes I:Lob-41 and I:Lob-42.

### 5.4.3 Execution of actions

The protocol data reveal considerable details on how the subject carried out actions. They show how the anaesthesiologist planned actions to be executed, how cues were sought to actually trigger actions, and how the concern list guided action executions. Mental activities involved in scheduling the order of actions to fit the actual situations were hinted at in many episodes, but this aspect of scheduling was not dealt with in the current analysis, partly due to the inadequate thinking-aloud verbalisation.

One thing worth noting about action execution is the flexibility observed. Even though the preparatory framework highlights the role of anticipation, acting in opportunistic manners is a hallmark of the anaesthesiologist's behaviour. Without proper treatment of the opportunistic characteristics, the preparatory framework would not be able to give a coherent account of the observed behaviour.

1 *Stacking an action*: Prompted by various cues, the anaesthesiologist planned future actions. Inevitably, these planned actions were verbalised in different levels of representations. Some of the verbal reports are very specific (*e.g.*, preparing nitroglycerin infusion bag); others are less so (*e.g.*, giving something to treat asthma). The stacked actions were waiting to be executed, pending on the specific triggering events. See Episodes I:Lob-4 and K:By-12.

2 *Triggering an action*: This is the case where the action was triggered by an easily identifiable event, which was in close temporal proximity to the action. At least two kinds of action triggering can be identified: (1) the action was stacked earlier and was triggered to be executed only at this moment; (2) the action was not stacked, in which case the action was usually a local response to the environment, such as in the case of being asked to change the operating table height. See Episodes I:Lob-15 and K:By-13.

3 *Formulating and seeking action triggering cues*: Experience provides the anaesthesiologist with the ability to seek cues that signify the fulfillment of preconditions for actions. Rather than assessing the situation comprehensively, the anaesthesiologist formulates and seeks the cues that are discriminative, *i.e.*, cues that can give indications whether or not an action should be executed. Discriminative cues often change with the actual situations, and thus the anaesthesiologist could formulate the cues according to particular settings. See Episodes G:Wp-22, G:Wp-24, H:Val-97, and H:Val-98.

4 *Modulating actions*: One of the ways for the stacked concerns to influence the anaesthesiologist's actions is through modulation. One can think of the execution of an action as a process of gradually specifying exactly what should be done and how an action should be executed. In general there are many degrees of freedom to be specified for an action to be executed in the spatial-temporal space. One role of the concern list in the anaesthesiologist's mental workspace is to *modulate* the action specification process. Such modulations in general can not be detected explicitly by direct observations. One has to infer from the verbal reports which concern had influenced the execution of actions. (More discussion will be provided on this topic in Part III.)

   For example, at the beginning of each case, the anaesthesiologist formulates concerns and makes general decisions about how to manage the patient based on the knowledge thus far. At the time of formulating a concern, the anaesthesiologist may or may not think of how to execute specific actions in light of the concern list. During the case, the concern list then modulates or shapes the execution of the specific actions. See Episode J:Sal-17 on page 273 and cross-check Episode J:Sal-1 on page 270.

5 *Flexible execution:* The anaesthesiologist exploits the resources available to him or her in an opportunistic manner, and often seeks the path of the least effort to execute actions. In one case, for example, when a planned action was triggered, the anaesthesiologist looked in the workplace for opportunities to delegate the task of action executions to others, and the action was released from the action stack. See Episodes G:Wp-13 and G:Wp-15.

### 5.4.4 Working with the mental workspace

To completely study the mental workspace—or the mental state of the subject—and its dynamics over time is certainly a desired research goal (*e.g.*, Carroll & Johnson, 1990, p. 77) but clearly very difficult, if not impossible. The protocol study partially answered the this need. So far, two kinds of identities in the mental workspace have been discussed: *concerns* and *actions*. Other identities, such as

- goals,
- options and choices,
- rules,
- expectations, and
- procedures

are not as prominent in the protocols, but nonetheless are believed to play important roles.

One could assume that the mental workspace functions in much the same way as the physical workspace: the subject could *place* cues in the mental workspace, *scan* it, and *prepare* and *reconfigure* it. However, unlike the operations on the physical workspace, these activities are not directly observable, and one has to rely on inferences from the protocols.

The following is a list of mental operations that were inferred from the protocol data.

### Preparing the mental workspace

Anaesthesiologists seem to have amazing capabilities to anticipate future events. A disease or a surgery name, for example, could trigger a chain reaction of recalling critical goals, prototypical patient conditions, options and choices available for achieving goals and resolving concerns, and materials that typically require special arrangement (either because of the lack of immediate availability or because of the time taken to prepare). These activities fall into the areas M1, M3 and M4 in Figure 4.5. Here are some examples from the protocol data:

1 *Reviewing options*:
See Episode H:Val-36 on page 220. In this case, the anaesthesiologist entertained the option of asking the surgeon to help if he were to fail to place the CVP catheter. One has to realise that such an option relies on the anaesthesiologist's familiarity with the surgeon, as well as with the specific surgery (*i.e.*, an open-heart surgery). Such an option does not exist, for example, in a brain surgery.

2 *Reviewing choices*:
Choosing between vecuronium and pancuronium as a muscle relaxant is often a decision to be made when the surgical length is uncertain. See Episode I:Lob-18 on page 256. The anaesthesiologist in that case was aware of the choice at the beginning of the case, and sought further information to make the decision.

3 *Reviewing goals and concerns*:
As a case evolves, some concerns are resolved whereas others are not. The protocol data actually show the review of concerns and goals towards the end of a case in Episode H:Val-112 on page 245. In that espisode the anaesthesiologist verbalised his review of the concerns that either had been resolved and eliminated, or waited to be resolved.

4 *Stacking expectations*:
Expectation plays a central role in the anaesthesiologist's monitoring activities. A mismatch between what has been expected and what is observed could alert the anaesthesiologist to look for signs of troubles. It was found that the anaesthesiologists often did not wait passively for new information to make an assessment. Instead, they set up expectations and processed the expected events in advance with respect to the particular situations, as in Episode H:Val-63 on page 230. In that episode the anaesthesiologist expected that the surgeon would cause irregular ECG readings as the surgeon was going to cannulate the heart. Because of this, the dysrhythmias, if observed, would not require treatment. See also Episodes H:Val-80 and H:Val-12.

Expectations also set the stage for effective interpretation of observed variables, as in Episode K:By-9 and K:By-11. In this case the anaesthesiologist expected that the reading of PA pressure would be high, and when later PA pressure *was* found to be high, the interpretation was quick and straightforward.

The execution of an action often triggers the expectation of the desired effect of that action. The confirmation of that expectation becomes the focus of monitoring behaviour after the completion of an action, as in Episodes G:Wp-22 to G:Wp-24.

5 *Preparing general guiding rules*:
The protocol data show that anaesthesiologists prepared general rules as a result of reviewing the patient conditions and surgical requirements. These general rules do not affect specific actions, and, similar to the role of concerns, they provide guidance and modulation for actions. A good example is in Episode J:Sal-1, where the general rule of using less anaesthetics was formulated, even though the anaesthesiologist may not have made the decision about the exact dosage. Episode L:Bone-10 provides an example of general rules for monitoring.

### Scanning the mental workspace

Indications of activities associated with scanning the mental workspace, although not available for direct observation, can be inferred from the protocol data. These activities presented themselves in the following manner: the anaesthesiologist seemed to realise suddenly that something needed to be done, and neither the post-case interview nor concurrent probing showed clear triggers for the action. An alternative inference to scanning the mental workspace would be that the anaesthesiologist was reminded upon seeing something in the physical environment. Either of the two inferences would suggest that the anaesthesiologist was reviewing actions to be taken and rehearsing those actions in the actual settings (*i.e.*, materials, arrangement, preconditions, etc.).

The following two examples show how the anaesthesiologist detected information and material needs through the rehearsal of future activities:

1 Episode H:Val-82 on page 236. The anaesthesiologist was thinking of a step in the off-pump procedure: activating platelets. He had noticed that the patient record contained a dated platelet count (several days ago), but a new test would take a long time. After detecting the information need well in advance, he could order a new test if no recent platelet count was available.

2 Episode H:Val-76 on page 233. The anaesthesiologist was reviewing the post-bypass patient management and was thinking of using a drug (phynelephrine) to deal with hypotension. While examining that option, he detected a material need and started preparing the drug.

Such activities of examining future actions and options can be looked upon as a “flashlight,” scanning the mental workspace (area M3 in Figure 4.5). As a case evolves, actions are instantiated gradually in detail, and missing elements (both in terms of information and of materials) are supplied before actions are executed. The apparent ease in the observed behaviour could be the result of using “looking ahead” and “staying ahead of the game” strategies.

### Formulating and using local rules

Some interesting behavioural patterns about the formulation and the usage of *local rules* were found in the protocol data. Anaesthesiologists prepared local rules to guide their actions in simplified manners without having to go through complicated reasoning, as shown in Figure 5.3. By anticipating a future event, the anaesthesiologist could, in advance, assess the significance of that event in the context of the actual circumstances, and then choose response action(s) to the anticipated event. Discriminative cues could also be formulated for the anticipated event. Two kinds of local rules can easily be identified: local control rules and local monitoring rules. The former provides *direct association* between a discriminative cue and an action, and the latter the association between a discriminative cue and the interpretation of the event that the discriminative cue signifies. These activities fall into areas M1 and M5 in Figure 4.5.

Here are several examples of formulating and using local rules.

1 *Triggering local control rules.* Evidence of using local control rules comes mainly

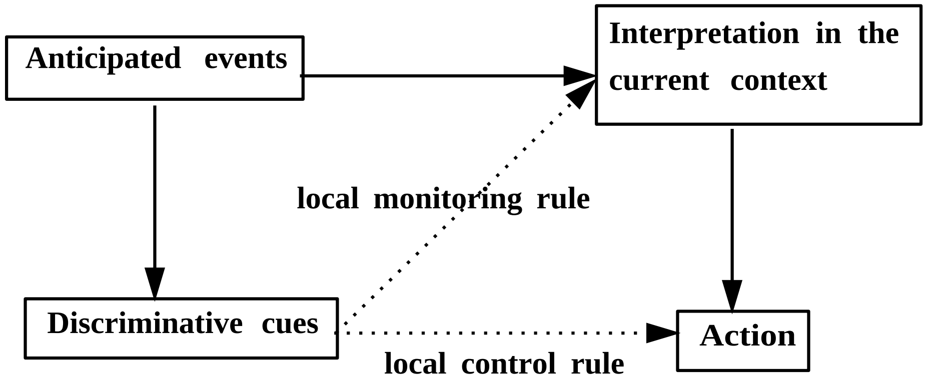



Figure 5.3: Preparing local controlling and monitoring rules. Through anticipating future events, the practitioner can process the significance of those events in the current context, and proper actions can then be chosen or decided. The cues indicating the events (discriminative cues) can also be anticipated. Thus *ad hoc* associations or *local rules* can be formulated between the discriminative cues, the interpretation of the anticipated events, and the response actions.

from self-reports, predominantly about the control of the depth of anaesthesia.[5] See Episodes G:Wp-53 and J:Sal-24. It is suspected that a wider usage of local control rules could be found if the thinking-aloud method could be applied more effectively.

2 *Stacking local monitoring rules.* In the community of anaesthesiologists, it is often said that one should take an "approach," at the beginning of a case, towards the patient monitoring—*i.e.*, how the monitoring parameters should be selected to obtain necessary information in a most cost-effective way. One result of this selection is the local monitoring rule: what monitor provides what discriminative cues. See Episode L:Bone-10. In that case, due to the large amount of expected blood loss, fluid management became a critical task, which required a good, economical (*i.e.*, informative yet easily accessible) indicator of the patient's blood volume. The anaesthesiologist utilised the blood pressure as a discriminative cue for the monitoring of the blood volume.

3 *Stacking local control rules.* As mentioned earlier regarding the role of the concern list, the execution of an action can be looked upon as a process of specifying the action in the spatial-temporal space. Through anticipating future actions, the anaesthesiologist could provide the specification information in advance, as in the Episode H:Val-60. In that episode, the anaesthesiologist worked on the dosage of the drug heparin well in advance. When the surgeon asked the anaesthesiologist to give heparin, he could just pick up the syringe and inject the pre-calculated dose to an i.v. port, without, at that moment, having to figure out or check the dosage against the patient condition, the length of the surgery, and other information.

### 5.4.5 Categorising and codifying cognitive activities

One central task in analysing protocol data is to *detect*, amid the linguistic or physical events recorded in the protocols, the mental activities that have brought about the observable activities. A commonly used strategy of accomplishing this is to codify the activities using cognitive labels (*e.g.*, Sanderson *et al.*, 1989). The intention is to remove the domain language description and to add in psychological descriptions. The large amount of trajecto-

[5] The depth of anaesthesia is a conceptual measurement indicating how *deeply* the patient is anaesthetised.

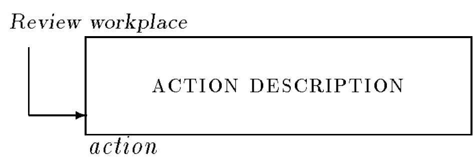
ries of events and activities can then possibly be reduced to a tractable set of flow patterns, which should better serve the purpose of identifying cognitive issues and answering research questions.

Summarising the findings described earlier in this section, ten basic ESF patterns were identified and are described below, along with their diagrammatic codings. Each of the flow patterns covers a category of activities. Note that instead of categorising all the activities contained in the protocols, only those activities analysed in the episodic analysis were included in the categorisation.

The following notation is used in the diagrammatic representation of ESF patterns:

- *slant* font—an operation (on mental or physical workspace).
- *italic* font—the label of an operant.
- sans serif font—fixed operant, *i.e.*, the operant is a constant and will not be substituted in use.
- SMALL CAPITAL font—variable operant, which will be substituted to actual values. In the protocols included in the appendices, the actual value is braced with single quotation marks.

1. Reviewing the *physical* workspace for its fitness or readiness for planned actions or procedures:

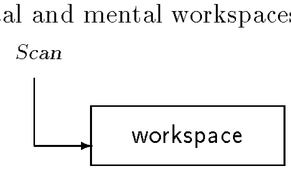



The actual activities include preparing materials and access for actions, procedures, and intended contingency responses.

2. Reviewing the *mental* workspace for its fitness or readiness for planned actions or procedures:

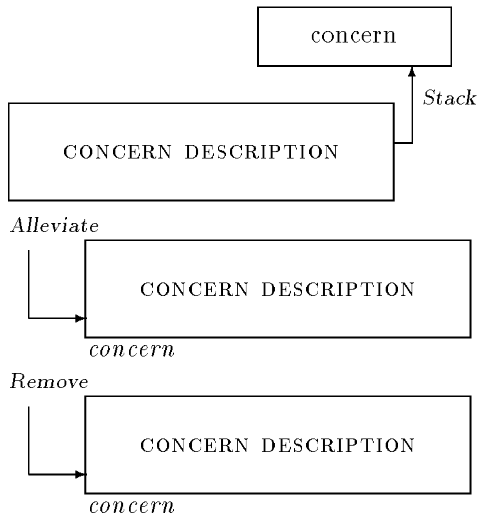

The actual activities include examining concerns and rules, and rehearsing planned actions.

3. Scanning the physical and mental workspaces:



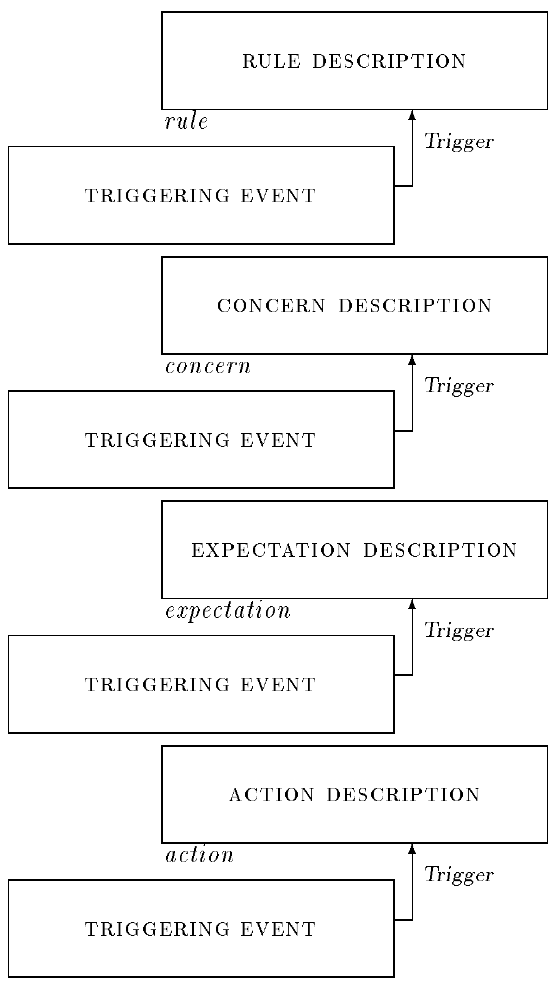

The actual activities include "reading" tasks from the physical and mental workspaces. Note that the latter contains identities such as actions to be taken, the concern list, and expectations. Scanning operation is different from reviewing operation in the specificity to actions. Reviewing is a process of examining either mental or physical workspace to see if it is ready for a *specific* planned or anticipated action, whereas scanning can be viewed as reviewing the workspace without specific actions in mind.

4. Stacking/Alleviating/Removing concerns:



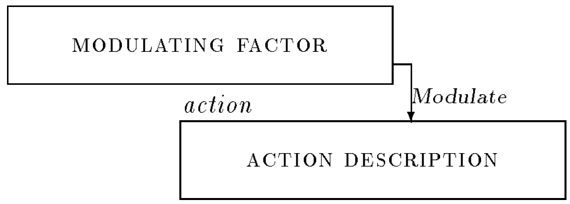

The actual activities include operations on the concern list: addition, removal, and alleviation.

5. Triggering:




The actual activities include triggering a rule, a concern, an expectation, and an action/procedure.

6. Modulating an action:

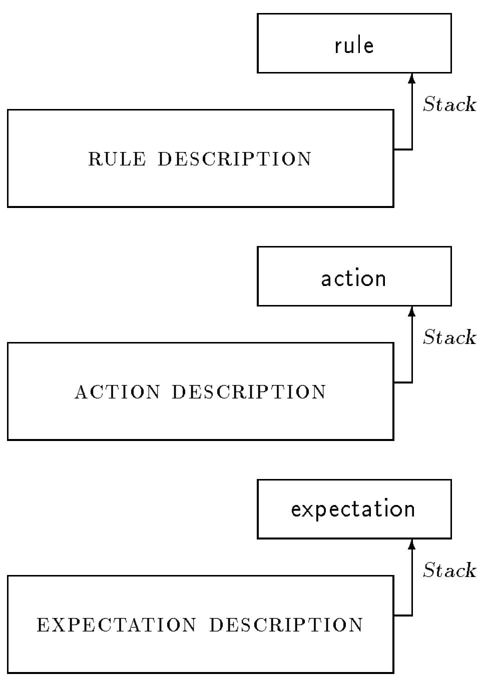



The actual activities include the execution of an action under the direction of a concern. In the protocol data collected, the modulation mostly took the form of deciding an exact dosage.

7. Seek cues:


The actual activities include seeking cues for action, for resolving a concern, or for confirming an expectation.

8. Stacking rules/expectation:

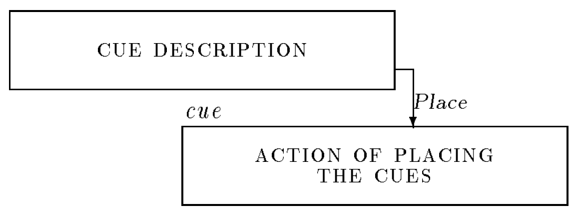



The actual activities include putting a rule, an expectation, or an action into the mental workspace.

9. Placing cues in the physical workspace:

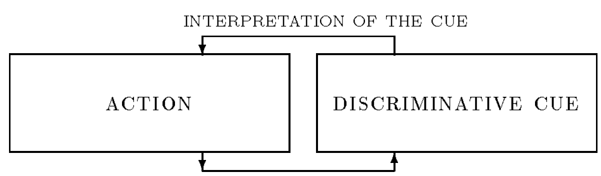
| | |
|---|---|
| 10:16:44 | Episode G:Wp-61 Pulse oximeter was found to be knocked off by the surgeon. |
| 10:21:20 | Episode G:Wp-62 The anaesthesiologist made the first request to the surgeon for a break of surgery to fix the oximeter. He had been watching the surgeon for a chance to do so. |
| 10:37:59 | Episode G:Wp-67 The anaesthesiologist made the second request. Again, the surgeon did not want to be interrupted. |
| 10:40:35 | Episode G:Wp-69 The anaesthesiologist opted for an alternate route to temporarily alleviate the concern over the dysfunctioned oximter. He ordered a blood gas test, which would have been ordered at a later time. |
| 11:03:14 | Episode G:Wp-73 Upon seeing that the surgeon was switched, the anaesthesiologist made third request. This time he succeeded and fixed the pulse oximter. The concern was resolved. |

Table 5.4: Episodes in the pulse oximter thread. See Appendix G for more details.




The actual activities include placing cues for actions.

10. Applying local control rule:




The actual activities include applying the control rule to regulate the patient status.

Apendices G to L contain the result of applying this coding scheme.

### 5.4.6 Looking beyond episodes: Thread analysis

The final analysis of the protocol data in this thesis is to examine the protocols in terms of *thread*. The idea of the thread analysis is to reveal how the anaesthesiologists made use of the mental and physical workspace in organising their activities over a *larger time duration*. Note that the thread analysis still remains context specific, but at a molar level in comparison with the ESF study.

Each thread encompasses a number of episodes, which are usually separated in time. One can easily identify several prominent threads in every case. Some of them are relatively plain and linear. For example, in the case in Appendix G, a key monitor (pulse oximeter) was unintentionally displaced and disabled (see Table 5.4). Thereafter the subject was seeking opportunities to resolve the concern (over the loss of the monitor). Others are quite complicated. For example, in the case in Appendix J, a key concern was about the patient's weakness. The thread of alleviating that concern contained the majority of the episodes in that case (during induction, maintenance, and recovery).

Three threads of activities in the protocol data are used to illustrate some of the central characteristics of preparatory behaviour that are either only partially represented or absent in the episodic analysis. These three are selected because of their representativeness and their relative "easiness" for the reader to appreciate.

Episode I:Lob-4 and Lob-5. The patient was found to have uncontrolled hypertension, and the anaesthesiologist anticipated large swings of blood pressure during and after the induction. She planned to use lidocaine to block the patient's response to the induction. In case that the blood pressure was still too high after using lidocaine, she planned to use nitroglycerin. She proceeded to prepare the nitroglycerin infusion bag and set the bag up so that if she needed to use it, all she had to do was to plug it into an i.v. port. These decisions happened *before* the case had started (the preparation of the nitroglycerin infusion bag was actually done during the preceding case).

Episode I:Lob-20. Just before the induction, the anaesthesiologist prepared the lidocaine syringe.

Episode I:Lob-21. The anaesthesiologist gave a relatively large dose of fentanyl in an effort to block the patient's response.

Episode I:Lob-23. The patient's blood pressure was high. This triggered the action of giving the patient some lidocaine.

Episode I:Lob-28. When giving Propofol, the anaesthesiologist used a large dose in reaction to the patient's high blood pressure.

Episode I:Lob-29. The induction phase was over. The anaesthesiologist gave a retrospective account to the thread of hypertension. She did not use the nitroglycerin infusion, because, during the intubation, the patient's blood pressure was satisfactory.

Table 5.5: Episodes in the hypertension thread. See Appendix I for more details.

### Examples

**1. Uncontrolled hypertension** This thread occurred in the case described in Appendix I. Table 5.5 lists major episodes in the thread. The ESF in Figure 5.4 illustrates how the anaesthesiologist prepared response rules and materials for the anticipated problem of hypertension. The ESF in Figure 5.5 represents the major activities in the thread.

This thread (hypertension) highlights both the role of preparatory behaviour and of local feedback. The precursor of uncontrolled hypertension triggered the concern of high blood pressure (BP) during the induction. The anaesthesiologist resolved the concern by formulating three rules: blocking the patient's response using large doses of induction drugs, using lidocaine if BP is still high, and using nitroglycerin infusion if the above measures fail. The latter two rules were contingency responses and were to be triggered only if the situation warranted. Nevertheless, the anaesthesiologist prepared materials and access for deploying these two rules, as when BP does go too high, the time pressure will be high as well. Saving time is crucial.

At the start of the induction procedure, the anaesthesiologist had outlined her options, which were prepared with little time pressure. The decision when responding to the anticipated problem of hypertension would be a matter of matching-and-triggering, even though there are many ways in which she could treat the same problem. The cues she looked for would be the easily available blood pressure readings. The needed materials and access were ready. The scale of the decision problem was considerably smaller than it would otherwise have been if the anaesthesiologist had to evaluate factors such as drug complications, patient allergies, the medication history, cost, availability, and so on, all under time pressure. She would have had to evaluate readings from sources in addition to the blood pressure monitor to make a situation assessment. Thus the seemingly simple, passive response (injecting lidocaine after reading high BP) in Episode I:Lob-23 (see Table 5.5) is in fact a result of preparation, and the response to the problem of high BP reading had started before the patient was even brought into the OR, long before the problem actually occurred. The same statement could be made if the anaesthesiologist had to use nitroglycerin infusion.

During the execution of the routine procedure of induction, the concern of hypertension modulated at least two of the steps through increasing doses. Dosage and timing are two exemplary parameters through which concerns can modulate actions.

In terms of the preparatory framework (Figure 4.5 on page 61), this thread demonstrates

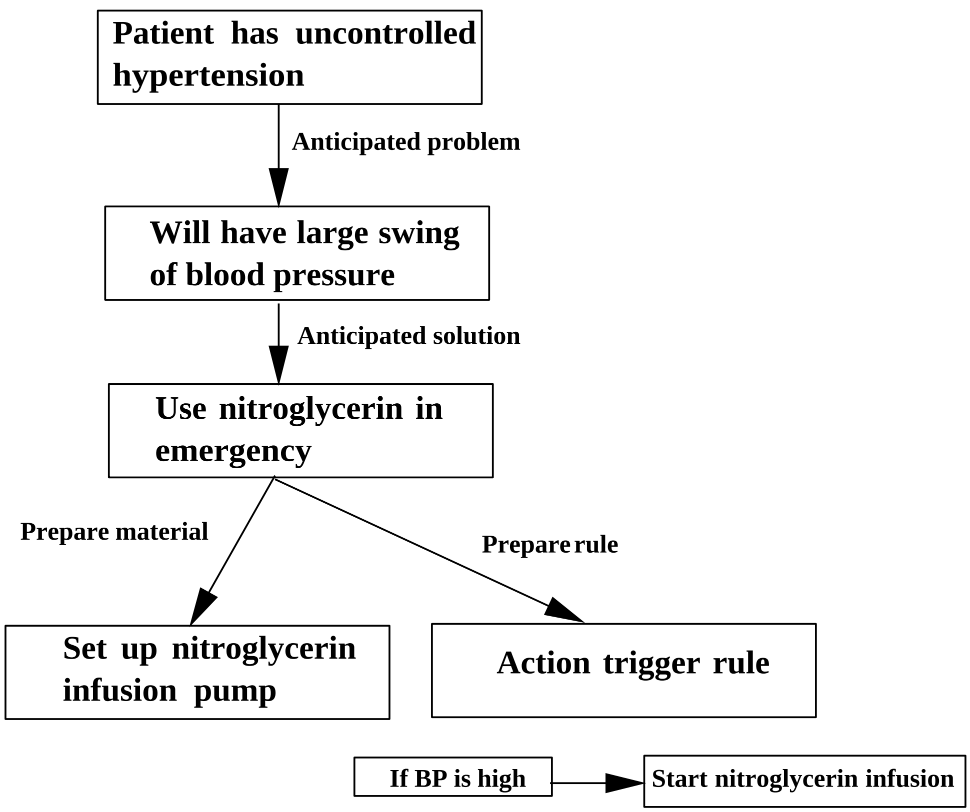



Figure 5.4: Preparing contingency response. The anaesthesiologist prepared not only contingency response rules, but also materials needed for implementing the rules.

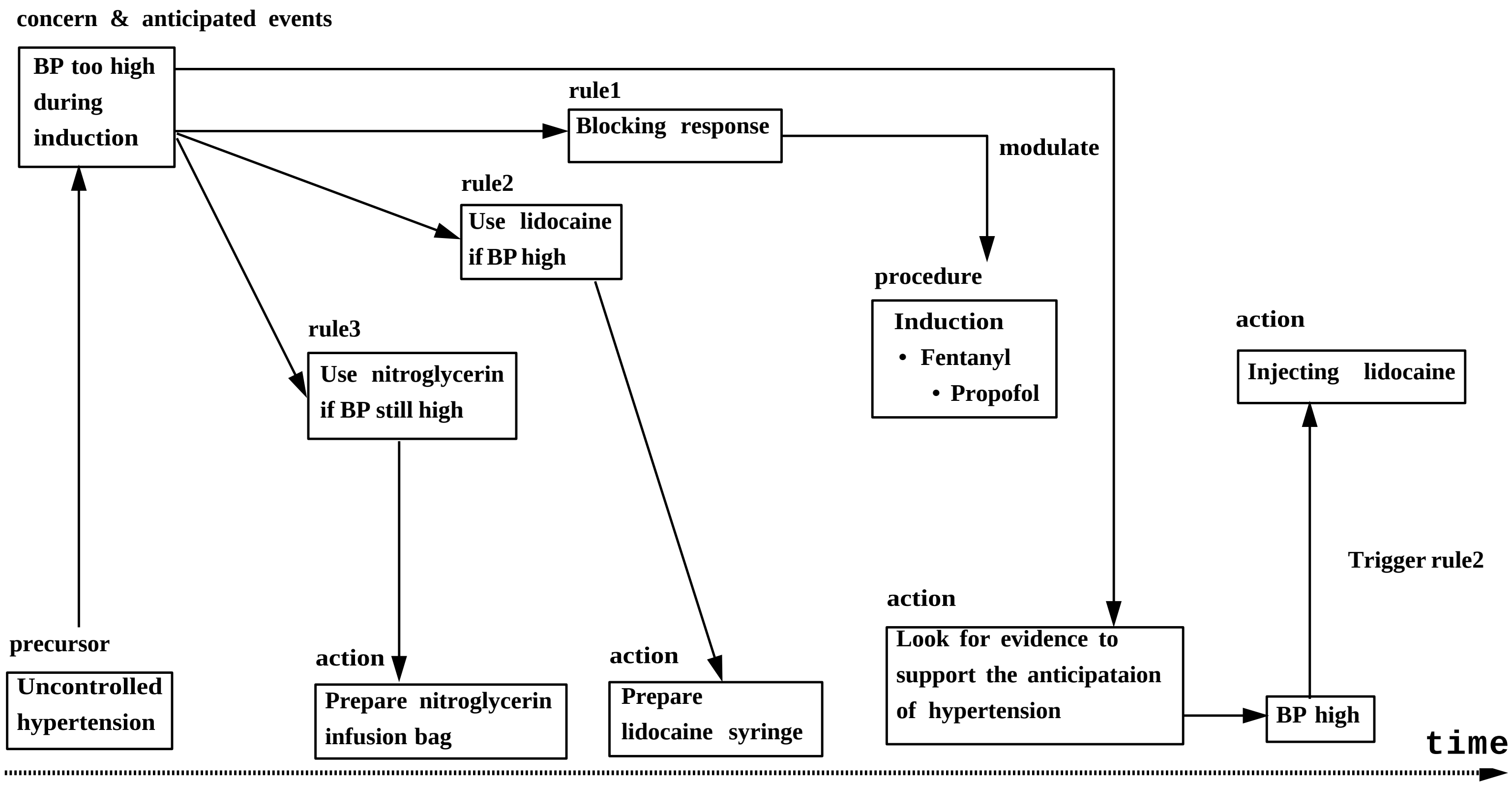



Figure 5.5: The ESF for the hypertension thread. This thread illustrates how a concern influences later actions. Rules and materials are prepared for effective response to anticipated events; routine procedures are modulated by concerns when executed. In particular, the action of injecting lidocaine in response to high blood pressure is prepared long before the triggering event.

Episode H:Val-21. The anaesthesiologist rehearsed the task of giving the patient Lasix and decided to inject it sometime after the induction. Remembering to carry out the action of injecting Lasix could be a memory burden, even though there are indications that the anaesthesiologist associated the event of the finish of intubation with the action of injecting Lasix.

Episode H:Val-24. The anaesthesiologist reviewed the task of giving Lasix. It was not the time that he should give it. He took out the box containing Lasix ampoules and placed it on the drug cart to remind himself (or the resident).

Episode H:Val-26. The ETT was placed and secured.

Episode H:Val-27. The anaesthesiologist gave the patient Lasix. Probing questions here showed that the timing of Lasix was chosen after the intubation because the anaesthesiologist wanted to avoid complicating the intubation procedure.

Table 5.6: Episodes in the Lasix injection thread. See Appendix H for more details. Lasix is a diuretic and is not an integral part of anaesthesia.

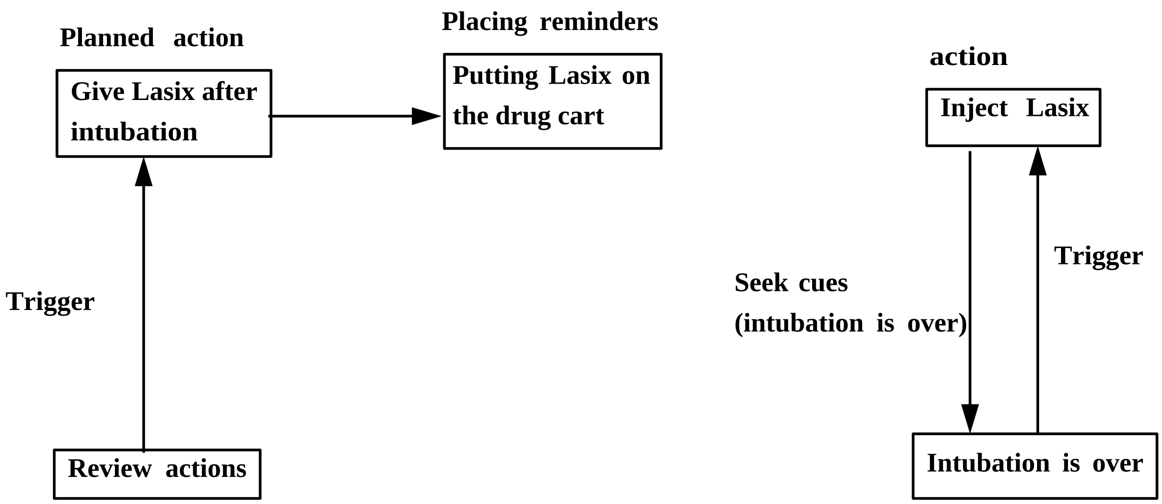



Figure 5.6: The ESF for the Lasix injection thread. Forgetting to give drugs that are not an integral part of anaesthesia is a concern in many cases. Apart from mentally rehearsing the action of giving this type of drug, anaesthesiologists utilise the physical workspace to remind them.

the activities in areas M1, M2, M3, M5, and P3.

Episode H:Val-76 in a different case contains a very similar kind of thread.

**2. Injecting Lasix** This thread is from the case contained in Appendix H. The major episodes in the thread are in Table 5.6, which are represented as an ESF in Figure 5.6.

The theme in this thread of injecting Lasix is making use of the physical workspace. Giving Lasix (a diuretic) is not an inherent part of anaesthesia. Forgetting to give it was perceived by the anaesthesiologist as a concern for this case. For this particular case, he decided that the proper time to give the drug was right after the intubation. Therefore it is highly probable that he mentally "*chained*" the task of giving Lasix with the event of the finish of intubation. One could hypothesise that he must have scheduled the two tasks of intubation and of giving Lasix in that order. One could also hypothesise that he made a rule: "when the intubation is over, give Lasix." However, deciding the action order did not seem to be the concern to the anaesthesiologist, nor is it the interesting aspect of this thread. What is interesting is the execution part of the action, *i.e.*, the way in which the anaesthesiologist reminded himself of giving the drug.

Episode J:Sal-1 . The patient was found to be very weak. The concern was the stress to the patient caused by anaesthesia.

Episode J:Sal-4 and Sal-5 . The anaesthesiologist sought information (from the surgeon and from the previous anaesthetic chart) that would help her to decide the minimum dosage of anaesthetic.

Episode J:Sal-9 The anaesthesiologist gave a small dose of fentanyl.

Episode J:Sal-17 The anaesthesiologist asked the surgeon for an estimation of surgery length and gave a small dose of vecuronium.

Episode J:Sal-18 The anaesthesiologist reported her general approach in managing this patient. In particular, she reported that she would use blood pressure to regulate the usage of anaesthetic, and she would prefer using less anaesthetic over using more.

Episode J:Sal-24 and Sal-34 The anaesthesiologist adjusted the level of anaesthetic vigorously to keep it in a narrow range.

Table 5.7: Episodes in the thread of regulating anaesthetic level. See Appendix J for more details.

In the OR environment, the anaesthesiologist has to respond to on-line events, which can easily disrupt what the anaesthesiologist is doing and disturb what is in memory. To ensure the task being carried out, he reviewed the list of the planned actions, and placed the Lasix box on the drug cart, which is constantly scanned by anaesthesiologists. The triggering cue for the action was the finish of intubation (or more precisely, when $CO_2$ was detected on one of the expired gas monitors). The Lasix box on the drug cart not only reminded the anaesthesiologist to give the drug, it also reminded him of the chaining of the task with the triggering cue: successful intubation.

The association of the triggering cue (*i.e.*, intubation is over) and the task (*i.e.*, giving Lasix) is certainly *ad hoc*. Making such an association would cause the action to be triggered easily by a convenient cue. The anaesthesiologist would not have to constantly evaluate whether he should give Lasix at that moment. This functional explanation of *ad hoc* association may admittedly have gone a little too far, but it is certainly a plausible explanation of how action is triggered in this and many other situations.

This thread demonstrates the activities in areas P1 and P2 in the preparatory framework. There are a number of other episodes in the protocol data showing the theme of placing reminders in the physical workspace (*e.g.*, Episode H:Val-82 and Val-97).

**3. Regulating anaesthetic level** The episodes (Table 5.7) in this thread are from Appendix J. In fact this thread includes the majority of the episodes in the case, but many of them are redundant from the viewpoint of analysis.

This thread demonstrates how a concern governed the way in which the anaesthesiologist interacted with the patient's physiology (see ESF in Figure 5.7).

After examining the patient, the anaesthesiologist determined that the major concern for this case was the potential stress caused by anaesthetic. As a result, the anaesthesiologist decided to use as little anaesthetic as possible. That would entail the task of finding what was the minimum level of anaesthetic for this patient in this particular surgery. The anaesthesiologist asked the surgeon directly for his estimation of the duration of the surgery,[6] and she checked anaesthetic charts from the patient's previous surgeries for the dosage used before. It so happened that the patient had had at least two surgeries almost identical to the current one.

Because the anaesthesiologist maintained the depth of anaesthesia at the minimum level, there was a risk of under-sedation. Thus during the maintenance phase of the case,[7] the

[6]Every case has a booking length, which is a rough estimate of the expected length.

[7]See the description of the maintenance phase in Section 3.2.2.

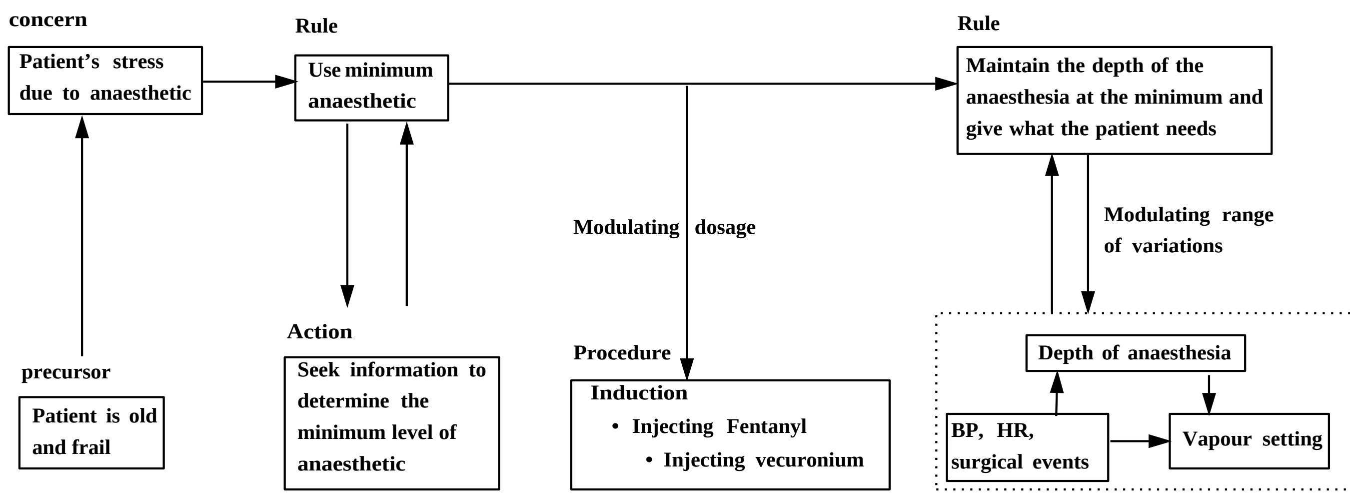



Figure 5.7: The ESF for the thread of regulating anaesthetic level. The patient was old and frail. A decision was made to keep the patient's physiological status within a narrow band. This thread illustrates how such a decision impacted the subsequent activities.

anaesthesiologist was working within a *narrow envelope* of the depth of anaesthesia. Consequently, the anaesthesiologist adjusted the vaporiser setting frequently, through a local feedback control loop on the blood pressure and heart rating readings, and through a feed-forward control loop on the observation of the surgeon's activities.

This thread demonstrates activities in areas M1, M3, and M5.

* * *

A thorough analysis of the protocol data from a knowledge-rich field requires an enormous amount of effort. Not only does one have to overcome the difficulties in understanding the events and activities, one has to be sensitive to the cognitive activities buried under the surface of domain description and be able to elicit these activities from the protocol data. The three levels of analyses in the protocol study took this challenge. These analyses identified not only a range of problem solving activities, but also some of the structures in the observed activities that illustrate how practitioners interact with the task environment.

## 5.5 Discussion

### 5.5.1 On the methodology of the protocol analysis

The term "protocol analysis" often has the intonation of analysis at a linguistic level, with the ultimate goal of explicit modelling. Tools have been developed to facilitate achieving that goal (*e.g.*, Sanderson *et al.*, 1989). This is partly due to the success of Newell and Simon's work (1972). However, such analysis of protocols is only one of many approaches to protocol data. The primary interest of the current protocol study is not to develop an explicit model of how the anaesthesiologist behaves in the OR. Rather, it is to enrich the understanding of an important class of problem solving activities: anticipation and preparation.

The methodology used in the current protocol study resembles the one promoted by Hollnagel *et al.*(1981), and emphasises the process of *abstraction* from case-specific data to generic patterns or strategies in the behaviour. Although there have been studies that used similar approaches (Pew *et al.*, 1981; Bainbridge, 1974), the current methodology examined the behavioural stream at levels ranging from micro-flow patterns of events and mental states to strategic behaviour of planning. Through the multi-level analysis, it is possible to investigate how practitioners organise their behaviour in the interaction with the dynamic work environment.

### 5.5.2 On the role of the preparatory framework

Understanding the behaviour in the interaction between a practitioner and the complex work environment is a formidable task. If one is restricted to only very limited access to behavioural data, most of which are indirect, such an endeavour is even more challenging. The anticipatory nature of human activities observed in the OR, and presumably, in other naturalistic settings as well, contributes greatly to the challenges facing us. The findings in the direct observation study essentially converge to a single message, namely that efficient responses to events in the environment, in many situations, depend on anticipation of those events and the preparation of reponses to those events. The proposed preparatory framework incorporates a number of activities involved in anticipation and preparation, and is critical to the understanding of the protocols recorded.

With the guidance of the preparatory framework, the protocol study attempted to make sense of an *indirect, reconstructed* record of the interaction between the practitioner and the environment. The role of the framwork in the protocol study is not so much of a "*template*" to a behavioural pattern as of a "*lens*" through which the *structure* in the behaviour becomes apparent. As it became clear in the analysis of the protocol data, in order to understand the role of anticipation and preparation, one has to analyse essentially every segment of the protocol data. Not only that, one has to deal with the characteristics of being opportunistic and flexible, as they are an intimate part of the human-task environment interaction.

The protocol study also reveals a basic nature of field studies. The observed behaviour is shaped jointly by a number of factors, among which are the environmental events, the subject's experience and preferences, and the observation process (tools and techniques). All of these made it necessary to observe behaviour in various tasking situations with different subjects, in order to have a large range of exposure to various kinds of behaviour.

### 5.5.3 On the findings

Using the concepts in the preparatory framework, the protocol study analysed eight cases done by five anaesthesiologists of various experience levels, with a total of 30 hours of audio-recordings and 880 episodes. The analysis of the protocol data strengthens the importance of the role of anticipation and preparation. The protocol analysis provides detailed examples of how concerns and rules functioned and were prepared. It also provides examples of how the physical workspace was utilised. The analysis of the protocol data at different levels of detail shows that the preparatory framework and the associated concepts are useful in revealing the underlying structure in the behaviour. This in turn illustrates how the practitioner organises the physical and mental workspace and responds through anticipation and preparation.

# 6

# The Study of Peer Review Protocols

Intellectuals solve problems, geniuses prevent them.

—*A. Einstein*

Trouble is near to those who do not plan afar.

—*Chinese proverb*

## 6.1 Introduction

The proposed preparatory framework (Figure 4.5) summarises the major findings in the direct observation study. It depicts the theme that many of the anaesthesiologists' mental and physical activities are preparatory. It shows the prominent role of the ability to anticipate future events, to plot action plans accordingly, to detect troublesome situations and obstacles, and to prepare mentally and physically for all of these. With the guidance of the framework, the subsequent protocol study (Chapter 5) analysed the protocol data and enriched the understanding of how anticipatory and preparatory activities facilitate successful interaction between the practitioner and the complex, dynamic work environment.

Arguments could be made, however, that the preparatory framework is only one of many ways in which one could interpret and account for the observed activities. Being preparatory may seem critical only to the observer, not to anaesthesiologists. On the other hand, if anaesthesiologists do value skill in anticipatory and preparatory activities, and they concur with the findings of the field study, then one could at least say that the framework identifies an important class of physical and mental activities. During the informal contact with the anaesthesiologists, there was abundant anecdotal evidence to support the statement that a significant portion of the skills in anaesthesia are to anticipate and to prevent. However, in order to find evidence beyond the anecdotal level, one has to anwer the question of how to "ask" the anaesthesiologists to get their opinions on the role of anticipation and preparation.

This chapter presents a study that indirectly "asks" the anaesthesiologists what they think of the role of anticipation and preparation. The study is also a study of verbal transcripts—the *peer review protocol* (PRP) study. The PRPs were recorded during case round discussions, which are held regularly by the staff and the residents to review previous cases for training purposes.[1] It was hypothesised that these case rounds would provide evidence to suggest:

[1] Case rounds were suggested to me by a number of anaesthesiologists after they had been studied in the direct observation study. After one or two cases of study, they understood the purpose of the field study better and felt that case rounds should provide valuable information on problem solving activities in anaesthesiology.

- the discussions in the case rounds focus mostly on anticipating problems, instead of on solving existing problems;
- the anaesthesiologists train residents to be sensitive to precursors to troublesome situations, and to be prepared for them;
- the participants will evaluate someone's performance in a case according not only to how he or she responds to problems that have occurred, but also to how he or she anticipates and prepares for problems.

Note that these case rounds were held in a *naturalistic* setting which is part of the "field" for anaesthesiologists, even though they were not taking care of patients. In other words, the researcher did not mediate the discussions nor change the format that the staff and the residents used in case round discussions.

## 6.2 Methods

### 6.2.1 A description of case rounds

Case rounds are held in hospital settings for various purposes, the most important of which is training. There are several formats for rounds discussions. Some rounds are formal and take the format of a lecture. The case rounds recorded in this field study were informal, and took place in a conference room (as opposed to a clinical setting). The central idea in these informal rounds is that one presenter presents a real or constructed case from real cases, then poses questions to the participants and solicits answers to the questions, as well as the basic principles behind the answers. The presenter can be either a staff member or a resident. Often various possibilities in treatment and diagnosis are explored. As a training method, these case rounds are highly valued.

The case rounds recorded in the present study all happened early in the morning, before the regular OR duties. Rounds lasted between 30 and 45 minutes, during which one to three cases were presented and discussed. Participants were mostly residents (from first to final year residents), but there was always at least one staff. The purpose of these rounds was specifically for training the residents.

A case presentation usually followed a "play-and-pause" mode. The presenter started with a description of a case, either in terms of a surgery to be done, or of a problematic situation to be tackled. If the case was about the responses to a particular scenario during anaesthesia, the events leading to that scenario were briefly presented. Thereafter the discussion was carried out in a highly interactive fashion, with almost everyone contributing to the questioning and answering. Naturally, easy questions were left to junior residents while more advanced questions were posed to senior residents, or even to staff members.

### 6.2.2 Data collection

Prior to the start of recording, consent was sought from the coordinator of the anaesthesiology residency program in the local hospital organisation, in which the studied hospital is a member.[2] The consent for attending and recording was a conditional one, pending the approval of those participating in the case rounds. The organiser of morning case rounds in the studied hospital was then contacted for the specific permissions for each case round. She was also asked to convince all participants that such recordings would not impair the function of the case rounds, and that the disturbance due to the recording, if there were to be any, would be minimal and could be ignored.[3]

[2] Because residents rotate among several hospitals in the city, a central coordinator is necessary for the resident training programs.

[3] The PRP study was postponed because of a single opponent to the recording of case rounds until later when she moved to another hospital.

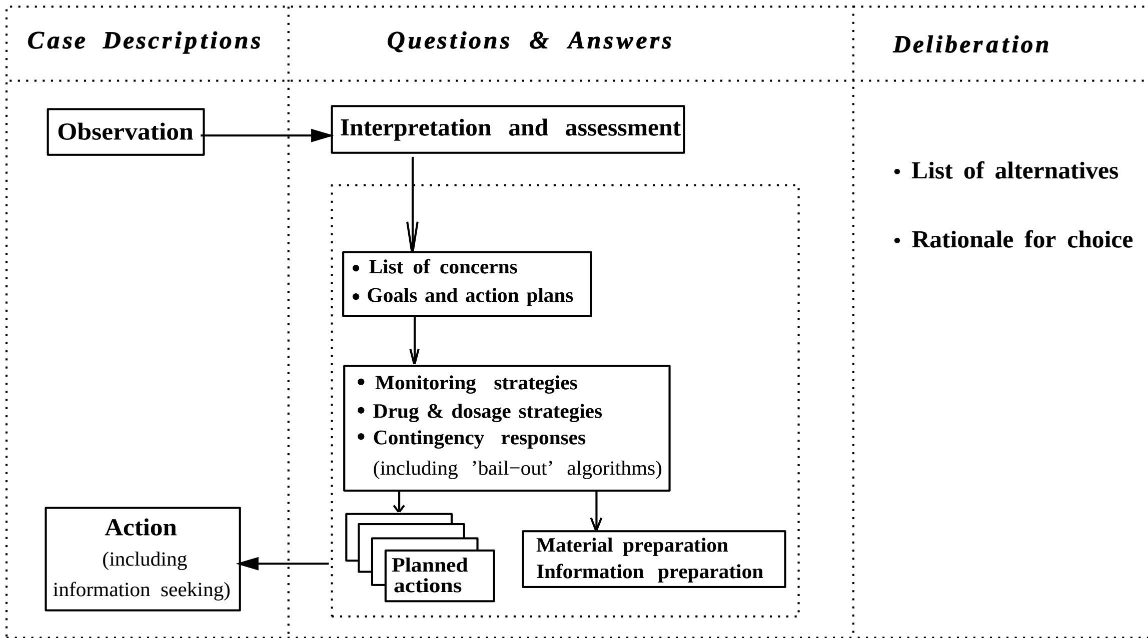



Figure 6.1: A schematic representation of case round discussions. It represents the structure of the discussions in the recorded case rounds.

After attending several case rounds, four sessions were audiotaped, which consisted of a total of ten (10) cases. In all cases, the presenter was a staff member. The recordings were then transcribed.

### 6.2.3 The processing of the transcripts

The processing of the transcripts was similar to that of the actual case protocols described in the last chapter. Due to the number of speakers and intense interactions, no effort was made to separate speakers in the transcripts. Instead, a single flow of discussion was charted for each case. The chart contains information on the evolution of events, formation of action plans, decision choices, actions, observations, and deliberations.

The charts so formed are similar to the event-state flows (ESFs) used in the protocol study, with the exception of the category *deliberation*, which will be described below.

In a case round discussion, the staff member often asks questions to test the general knowledge of the residents. These questions are related to the case but only indirectly. For example, when a solution is proposed, the staff member could pose the question "To what situations would this solution not be applicable?" Discussions of this kind are labelled as "deliberation."

After examining the PRPs, it was found that the discussions roughly followed the route of "initial problem" → "assessment" → "concerns and goals" → "deliberations" → "action plans." To a large extent, the charts drawn out of the discussions were in the format in Figure 6.1. Note that the arrows in the diagram represent the flows of the discussion, not decision paths or activity sequences. Figures 6.2 through 6.7 are example data for the recorded case rounds. Read them briefly before reading the summary below.

Because in case rounds events were condensed and only fragments of cases were reported and considered, the analysis tends to be simpler than that of actual cases.

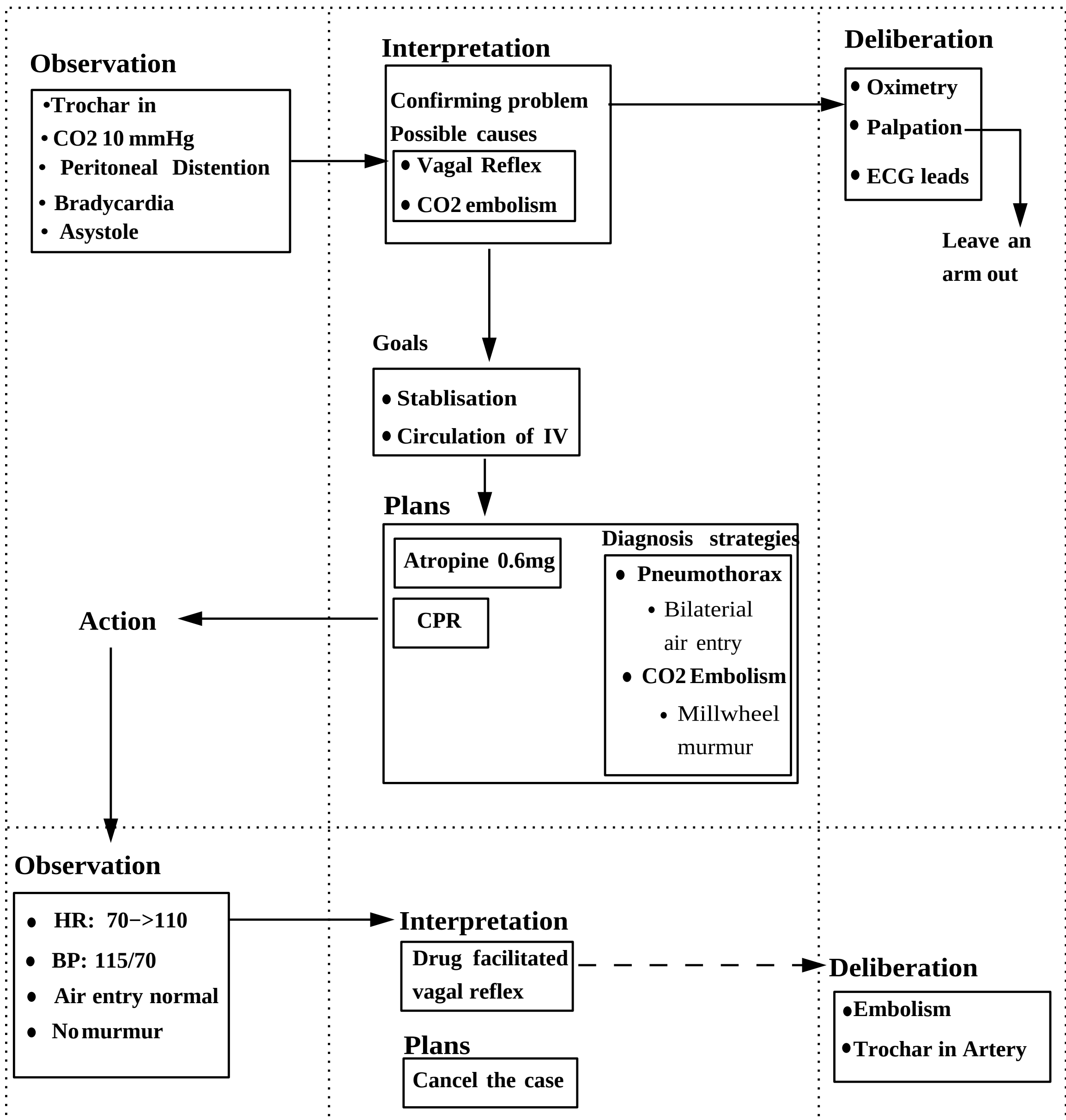



Figure 6.2: Case I: 32 year old, healthy female underwent laparoscopy. The patient was in a life-threatening condition and required immediate response. The theme of the discussion was the swift recognition of the problem and of the solutions.

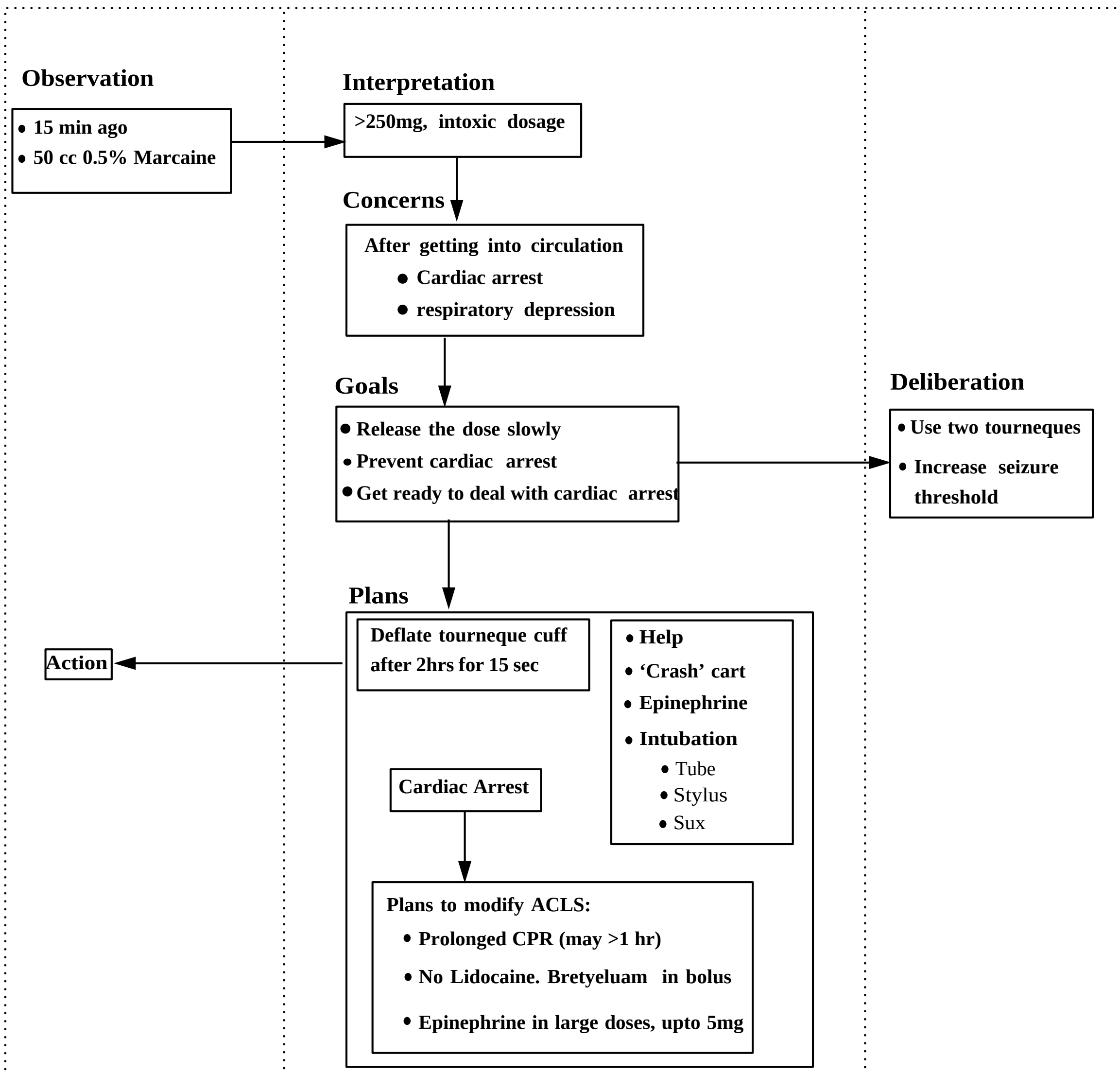



Figure 6.3: Case II: 18 years old, male, 60 kg, underwent ganglion removal surgery. The patient was given an overdosed local anaesthetic, and was in a steady condition. However, once the tourneque was deflated, the local anaesthetic would get into other parts of the patient's circulation and would have serious consequences. The theme of the discussion was the recognition of the problem and adequate preparation for the anticipated emergency situation (cardiac arrest). The preparation included both rehearsal/modification of procedures (ACLS) and materials.

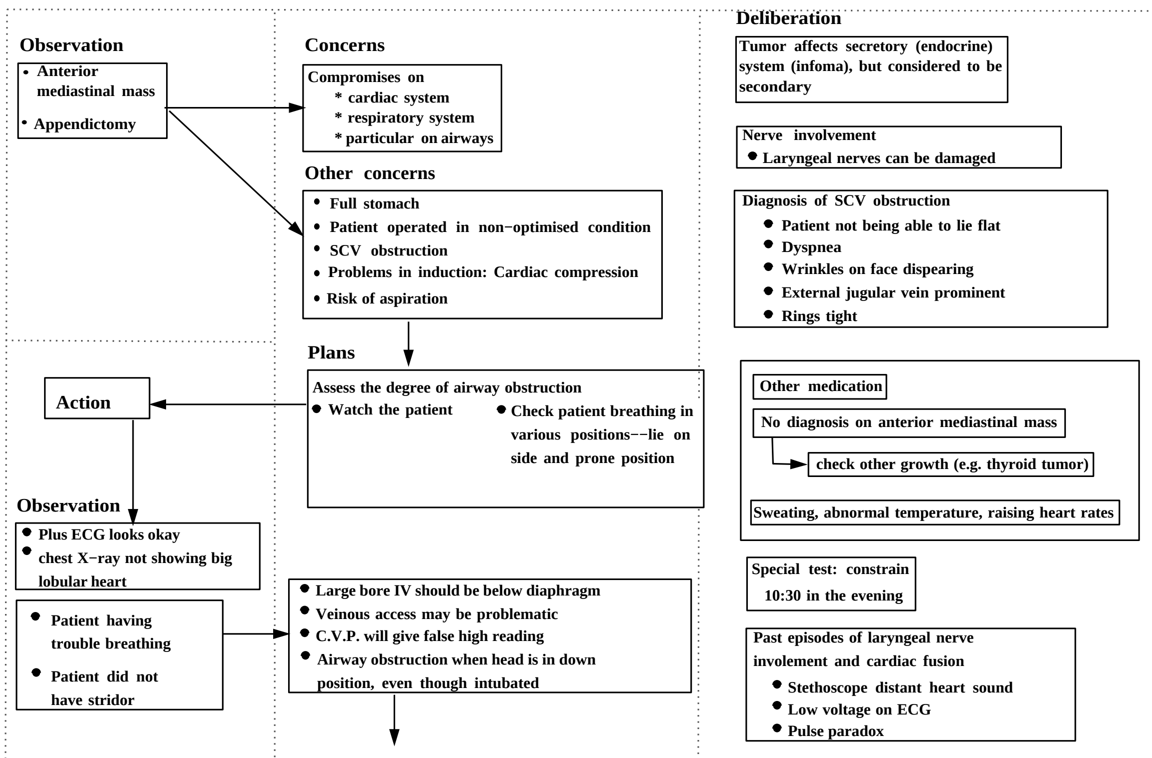



Figure 6.4: Case III (continued in Figure 6.5): Previously healthy 42 year old, male had dyspnea when lying flat supine. Chest X-ray showed a large anterior mediastinal mass. CT scan and pulmonary function test were ordered but not yet available. He was to have an appendectomy in the evening. The discussion was long for this case. Theme 1 in this case is the effecient recall of concerns given only a couple of key descriptions of the case (*i.e.*, appendectomy and anterior mediastinal mass). The discussion also shows how a rehearsal helped to generate guidance for actions (*i.e.*, using uncut tube in intubation). To be continued in Figure 6.5.

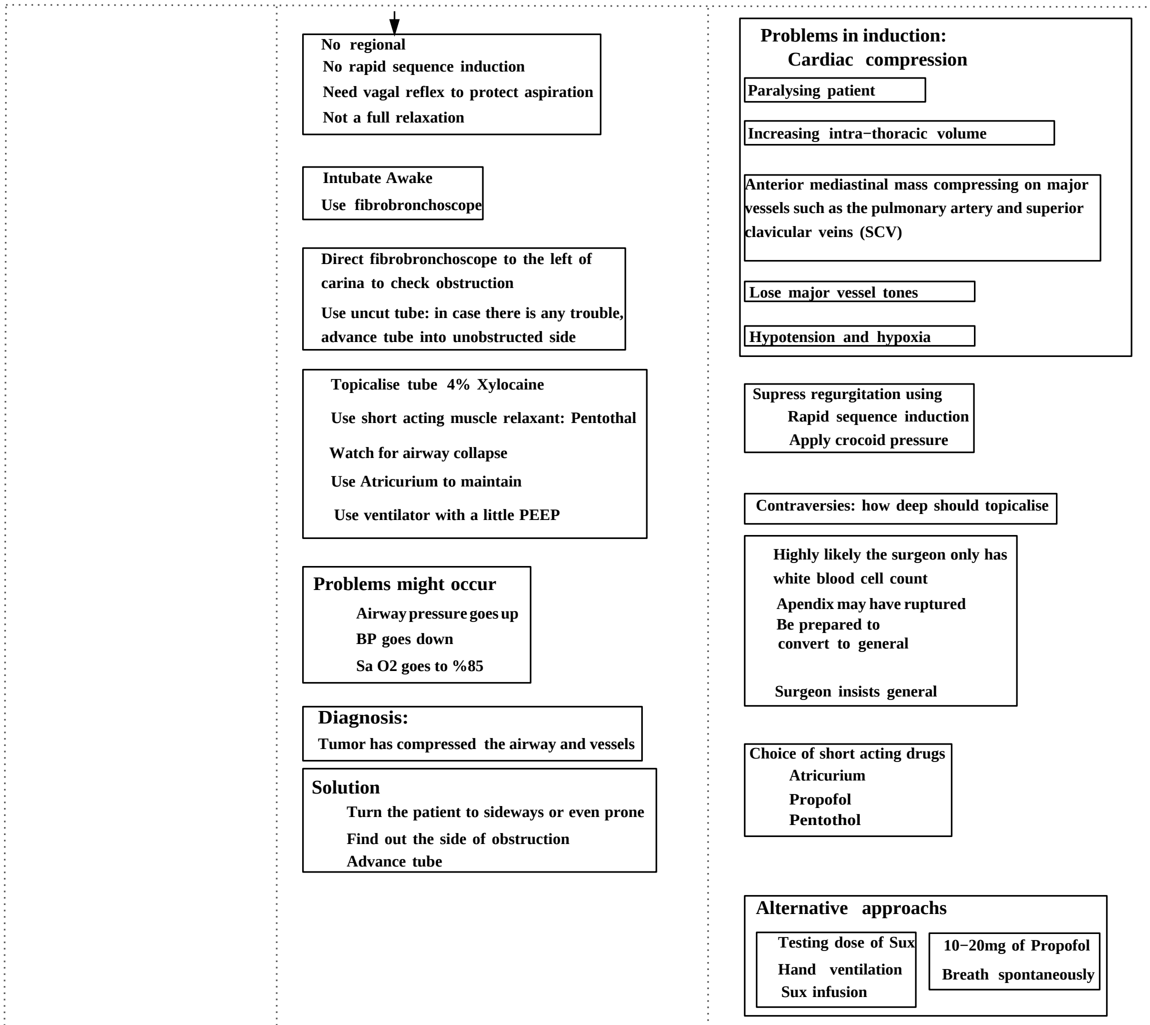



Figure 6.5: Case III: continued from Figure 6.4. Theme 2 for this case is the anticipation of airway problems due to the concurrent disease (anterior mediastinal mass). The anticipation includes the expected cue to indicate the airway problem ("airway pressure goes up," "BP goes down," and "$S_aO_2$ goes to 85%"), explanation to the problem ("tumor has compressed the airway"), and solution (*e.g.*, "turn the patient sideways or even prone").

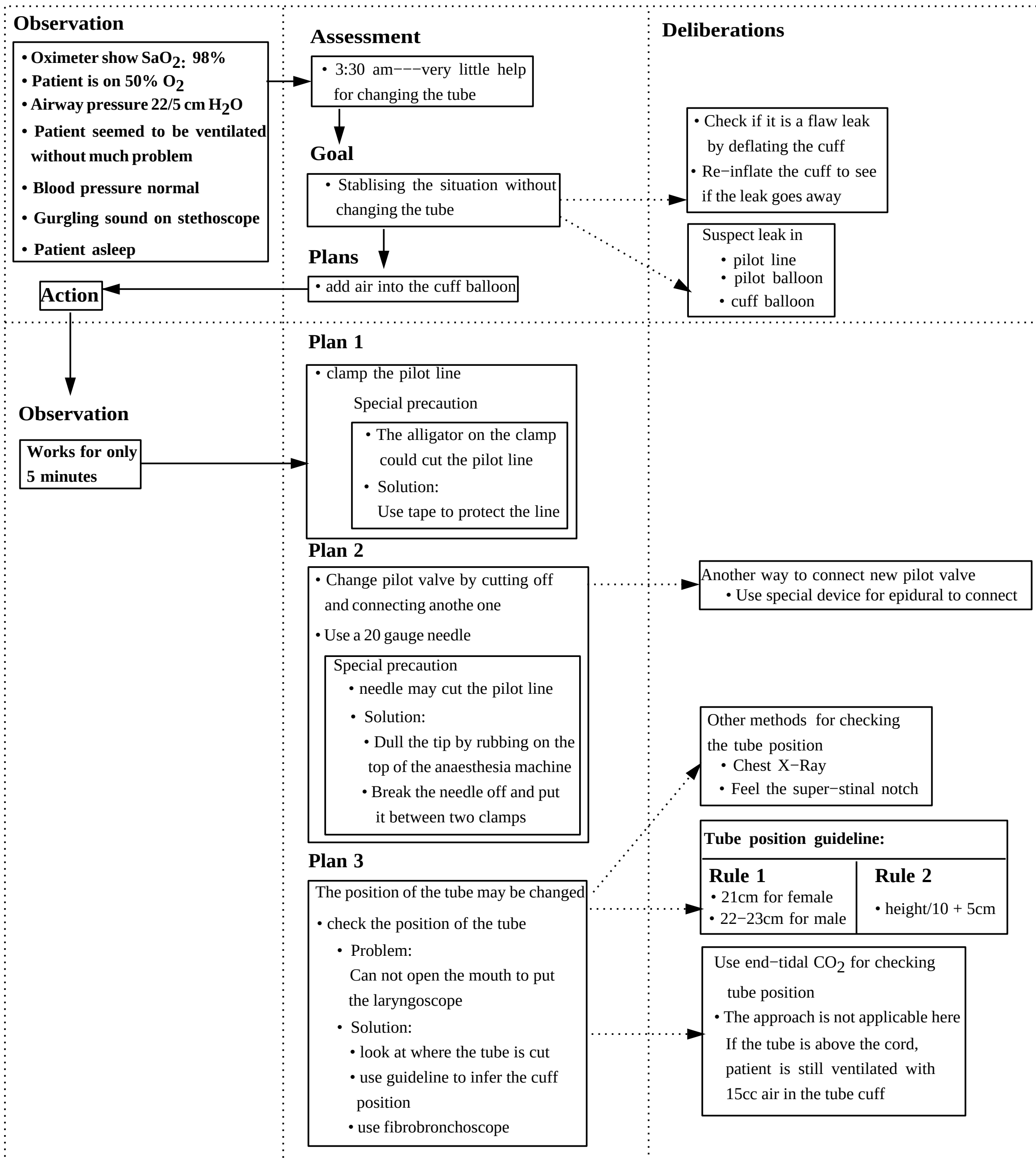



Figure 6.6: Case IV data (continued in figure 6.7): Called to ICU 3:30am for cuff leaks. The patient had a day and a night face revisit operation. The patient had difficult intubation due to previous operation and was intubated orally. The theme for this case is the recognition of concerns for planned actions. Some of these concerns were in the form of errors that one was likely to commit.

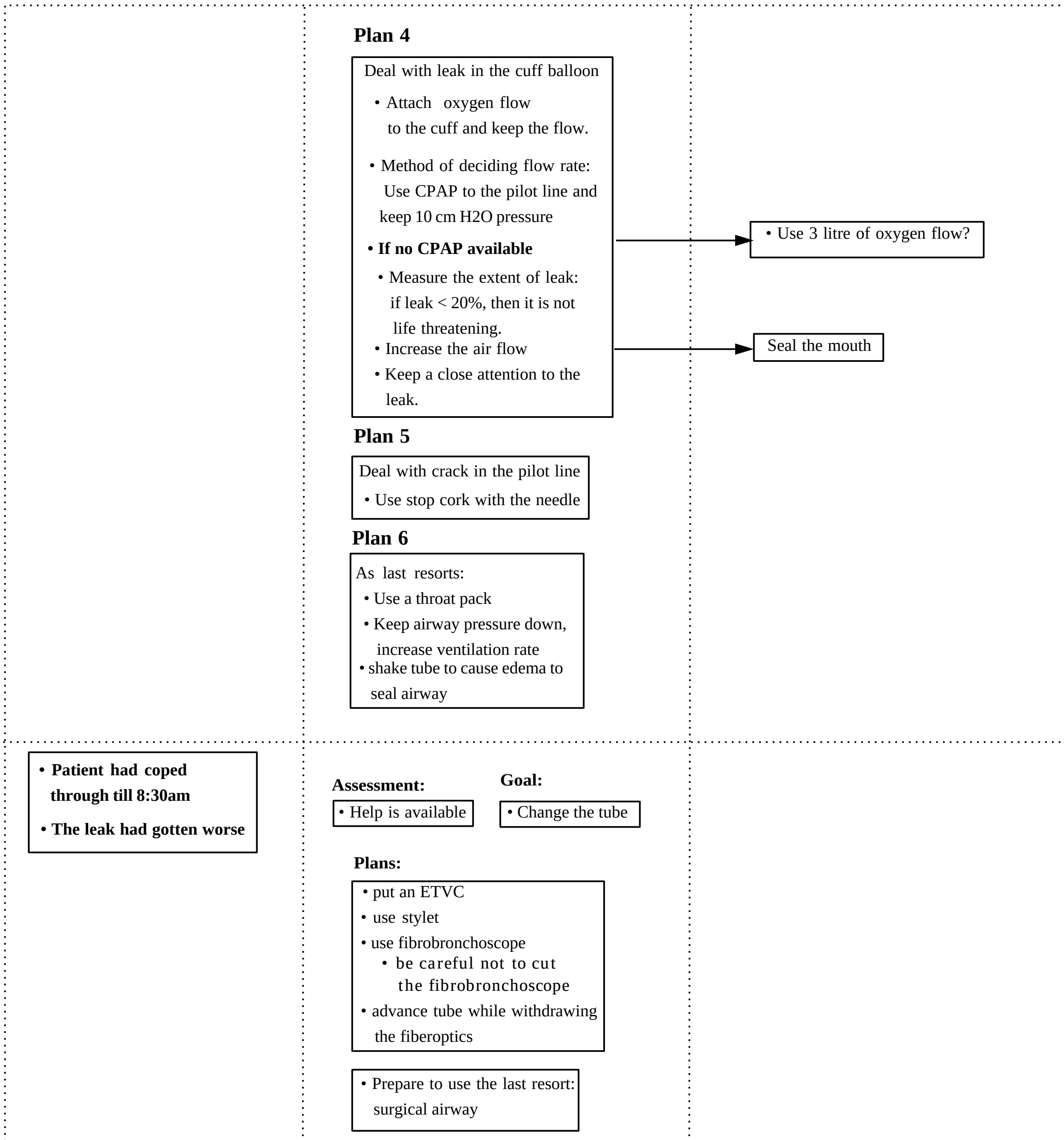



Figure 6.7: Case IV: continued from Figure 6.6.

## 6.3 Summary of the PRPs

Out of the ten cases recorded, three of them were about case planning, in which descriptions of the patient and the surgery were given and the participants were to come up with ways to do the cases. The remaining seven cases were about responding to an event or a critical situation. So three kinds of initial problems were presented to the participants: how to conduct an anaesthesia from the beginning, how to respond to a critical event, and how to respond to a situation that has the potential to cause serious consequences. With the exception of two cases, the discussions ended when the initial problem was solved and solutions evaluated—*i.e.*, further action and event sequences in the actual cases were not played to the participants. It seems that the presenter was not interested in examining complete cases, but only one or a few important aspects of a scenario.

### 6.3.1 Contents of the PRPs

The contents of the discussions can be broken up into the following categories:

- identification and review of goals and action plans;
- identification and review of concerns; and
- contingency responses and preparation of materials.

**Identification and review of goals and action plans** These discussions often followed those of concerns. When the initial problems were life threatening, however, the focus of the discussion was directed at the identification of goals and action plans: What is the desired state of affairs and what should one do? In these discussions, there was little said about anticipation. Rather, the skills stressed were how to stabilise the patient quickly and then how to diagnose the cause(s) of the event.

**Identification and review of concerns** When the initial problem was presented, the participants quickly generated a *short* list of *concerns* for the problem, and subsequent discussions revolved around these concerns. As mentioned in the last chapter, concerns can be obstacles to protypical procedures, anticipated critical events, or errors that one is likely to commit. For example, when the keyword "appendectomy" was mentioned in the initial problem, the participants immediately responded with the concern of 'full stomach,'[4] which in turn led to the concern of aspiration. The discussions focused more on the identification of the concerns than on the resolution of them.

Discussions of concerns were sometimes triggered by the review of an action plan. For example, the review of the plan of "clamping the pilot line" led to the discussion of the concern of "cutting the line by the alligator on the roller valve if the line is not protected." It is interesting to note that the discussions of the concerns associated with actions or plans sometimes focused on minute technical details (see Figure 6.6, page 104), as did the discussions of the resolution of these concerns.

**Contingency responses and preparation of materials** This category of discussion is about the anticipation of troublesome situations, and how one should prepare for them. An example will be used to illustrate the discussions in this category.

Refer to Figure 6.3. The presenter asked the participants to respond to a troublesome situation: the patient had received an overdosed local anaesthetic. The patient was not in danger at the moment, but would be after the tourneque was released to allow circulation. The potential consequences of the overdosed local anaesthetic getting into the circulation were anticipated by the participants immediately after the presenter gave out the dosage information. Note that although measures were planned to prevent cardiac arrest, the

[4] Almost all appendectomies are non-elective surgeries, and the patient was likely to have eaten food prior to the surgery.

discussion turned to the contingency scenario of a cardiac arrest and the preparation for that scenario. One part of the preparation was to gather physical materials and resources; the other part was to formulate response plans. Because of the special circumstances, the standard procedure for cardiac arrests—ACLS[5]—had to be modified, and the need for special drugs was detected when the contingency responses were examined.

The discussions in this case clearly show the emphasis on the skills in detecting the need for materials and for response plans. Note also that the discussion did not touch the details of the steps in ACLS, but only the *modifications* to ACLS.

### 6.3.2 Relevant findings

**Sensitivity to precursors of problems**

In general, after a case was presented, there was an instant recognition of important cues in terms of goals and concerns, which in turn set off a chain reaction of identifying other concerns. This is not so surprising. What is surprising is the ability of the participants to focus on a few detailed problematic spots in action plans and contingency plans, given that there were a vast number of other potential problems. The examination of a plan often focused on a couple of minute operational details, as if other things were easy to do and thus did not call for attention.

For example, there were a number of steps in treating a leaking ETT cuff (see Figure 6.6). However, the discussion at one point centred around how to clamp the pilot line. It turned out that to clamp a line in the OR, one tends to use a regular clamp, which has sharp teeth that can break the pilot line. Once the concern was identified, the solution seemed to be straightforward and obvious (wrapping the pilot line with tape).

By identifying the potential "pitfalls" in the chosen course of action, the anaesthesiologist could pay attention to them to prevent getting into trouble. It appears that part of the goal of the case round discussions is to train the participants to be sensitive to critical concerns.

**Efficient recall of concerns**

Another interesting observation from the case round discussions is the efficient recall of concerns. It seems that there are direct associations between situations or action plans and concerns, as in the case of associating an appendectomy with the concern for a full stomach. In many situations there seems to be no need for detailed mental simulation (or search) in the process of recalling concerns. This efficient recall of concerns gives the anaesthesiologist the ability to rapidly examine action plans and prepare accordingly.

## 6.4 Summary

The PRP study contains only a small set of data. Nonetheless, it provides some interesting information on where the mental activities are focused when facing a problem solving situation.

First, there is evidence from the case round discussions to support the hypothesis that the staff anaesthesiologists train residents to be sensitive *selectively* to precursors of troublesome situations. In other words, the anaesthesiologists value the skills of being able to detect precursors of problems. This partially answers the question posed at the beginning of this chapter about how the anaesthesiologist values the importance of anticipatory and preparatory strategies.

Secondly, in case round discussions, many problems posed to the participants are *not* to anticipate and prepare, but to *respond* to critical situations in efficient ways. This is in contrast to the studies done in the OR. It is rare in the OR for an anaesthesiologist to

[5] Advanced Cardiac Life Support.

get into a situation that he or she has not anticipated to some degree. It shows that the field observations in domains like anaesthesia does not cover all possible problem solving scenarios, especially those rare events. Other forms of studies (*e.g.*, retrospective reports of past criticial events and case round discussions) should be conducted to get a full picture of problem solving activities. One of the important aspects of the current field observations (either direct or with the help of mechanical recording devices) is that severe, unexpected incidents could happen more often were the practitioner not to employ anticipatory and preparatory strategies.

Unfortunately, the case rounds recorded did not actually evaluate the performance of the attending staff—*i.e.*, the anaesthesiologist who actually performed the case. Further PRP studies could settle the claim put forth here that the anaesthesiologist evaluates someone's performance in a case according not only to how he or she responds to problems that have occurred, but also to how he or she anticipates and prepares for problems (Gaba, 1991).

# Epistemology of the Field Study: Results and Concepts

# 7

> Designers often suppose that [the operator] uses rational, conscious processes .... An important task when studying process operator performance is to identify the repertoire of ingenious tricks which evolve in operators to avoid this.
>
> —*J. Rasmussen, 1976, p. 379*

## 7.1 Introduction

The study of peer review protocols (PRPs) marked the end of the field study on problem solving behaviour in naturalistic settings. This chapter summarises the findings from the three phases of the study (the direct observation study, the protocol study, and the PRP study), and discusses the concepts and the framework developed in the field study.

## 7.2 Epistemology of the field study

As stated in the introduction, the goal of the current study is to answer the question of "what problems are solved by anaesthesiologists." It adopted the naturalistic approach (as opposed to formal experimental approach), and used naturalistic observations assisted by audio-recordings as the primary method of obtaining behavioural data. Table 7.1 outlines the three phases of the field study. This section reviews each phase of the field study from an epistemologic viewpoint and addresses the question: What are the significant contributions of the field study?

### 7.2.1 The preparatory framework: A tool for capturing an important class of activities

The direct observation study can be viewed as a process of generating a framework for capturing important aspects of problem solving activities in that domain. The direct observation study started with a very general question: "What problems are being solved by the anaesthesiologist?" It chose to answer this question through naturalistic observations. Apart from being a necessary step for familiarisation with the domain of anaesthesiology, it was also a process of exploring various aspects in anaesthesiologists' activities. By this nature, the direct observation study was *not* to confirm existing hypotheses, nor to validate any models. Instead, it was set to answer a "what" question.

Patterns of activities were synthesised through informal contacts with anaesthesiologists and through direct observations in the ORs over a period of two years. As depicted by

| *Phases of the field study* | *Settings* | *Data sources* | *Analysis procedures* | *Duration* |
|---|---|---|---|---|
| The direct observation study | Operating rooms | • Naturalistic observations<br>• Informal contacts<br>• Domain textbooks | • Iterative synthesising | 2 years |
| The protocol study | Operating rooms | • Notes of naturalistic observations<br>• Pre-operative interviews<br>• Post-operative interviews<br>• On-line audio recording<br>• Concurrent probing | • Episodic analysis<br>• Event-state flow analysis<br>• Thread analysis | 1 year |
| The peer review study | Conference room | • Audio recordings of case discussions | • Charting the flow of discussions<br>• Identifying focuses of discussions | 2 months |

Table 7.1: Chronology of the field study. Note that all settings are naturalistic, that is, not contrived for the purpose of studying.

Figure 4.1 (page 57), the process of synthesising these patterns was iterative: findings were not only the results of observations, but also the guidance for further observations.

The direct observation study was also an iterative process of *implicit* falsification: findings and descriptions from earlier observations were applied to newly observed activities, and were modified if they failed to capture the patterns in the newly observed activities. From this point of view, any criticism that observational studies are intrinsically subjective is not valid. Although it is true that the findings of the direct observation study did not go through rigorous testing in a traditional sense, and did not provide readers with access to the data from which the findings were derived, these findings were the result of a long-term *empirical* observation of a number of cases done by a number of anaesthesiologists.

During the study, it was observed that a large number of problem solving activities could be categorised as anticipation and preparation. In other words, not only do the practitioners have to respond to the events in the environment, they also anticipate future events and prepare responses to these anticipated events. The implication of this observation is profound: In order to find out what problems are solved by anaesthesiologists, one needs to look beyond the so-called event → mental process → response (EPR) cycle, that is, the activities involved in responding to an event in the environment *after* perception of that event. Thus, in studying the behavioural stream—the flow of activities over time—one cannot cut the stream into isolated cycles of EPR and investigate only how the practitioner connects events with responses. Consequently, one can not use the "traditional" approach of first identifying events in the environment and then finding out how the practitioner responds to those events.

This "non-event-driven" characteristic of anaesthesiology poses special challenges to the field study: If the practitioner behaves in an anticipatory and preparatory manner, how can we *detect* and *capture* the anticipatory and preparatory activities in the behavioural stream? What effects do these activities have on the subsequent responses?

A framework was proposed that categorises the observed patterns into eight types of activities and *at the same time* illustrates the relationships between these activities and those identified as responding to the events in the environment. Two key concepts were developed in the framework: the *mental* workspace and the *physical* workspace, and they enabled effective descriptions of the preparatory activities. Three of the eight types of activities are related to arranging the workplace (preparing the physical workspace) and the rest to establishing a proper mental state (preparing the mental workspace).

Instead of being a model of how anaesthesiologists solve problems, the preparatory framework provides a guide to those activities that the anaesthesiologists may perform in order to anticipate and to prepare. It also allows us to see readily those activities that have the effect of *facilitating* successful interactions between the practitioner and his or her environment.

### 7.2.2 The protocol study: A search for structures in behavioural streams

The data collected from the field in the protocol study allow one to repeatedly examine behavioural streams in detail. Due to the nature of the task environment (the operating room), it seems clear that analysis of the protocol data solely at a linguistic level would not be fruitful, and the analysis of the protocols had to examine the protocols at a molar level. The protocols obtained do not describe a detailed process of problem solving, but rather, a series of fragmented *hints* of what *might have happened* during more overt problem solving. Thus interpretation of the protocol data requires not only knowledge about the domain of anaesthesiology, but also a set of conceptual tools that enable one to identify the behavioural structures through which the anaesthesiologist organises his or her physical and mental activities to achieve a hierarchy of goals (refer to Figure 5.2 on page 76).

As mentioned earlier, the preparatory framework functioned as a "lens" for searching for anticipatory and preparatory activities in the protocol data. Detailed behavioural patterns were identified about how anaesthesiologists prepare physical and mental workspaces and how the preparation of these two workspaces facilitate the interaction with the task environment. Because of the latter, the importance of the preparatory framework lies no longer solely in the studying of preparatory behaviour. The patterns discovered there also provide a basis for revealing underlying structures in the behaviour: how the practitioner—a proficient actor in the task domain—organises the behaviour to achieve his or her goals, subject to physical and cognitive limitations.

In presenting and categorising these patterns, several conceptual operations on the physical and mental workspace were proposed. These operations were used in annotating and coding the protocol data from a range of cases done by several anaesthesiologists, both as a way of testing the adequacy of the proposed operations (see codings in Appendices G to L) and as a set of tools for making apparent the behavioural structures reflected in the protocol data. As a result, the protocol study enriches the understanding of preparatory behaviour in the context of managing a complex, dynamic system and coping with uncertainties in the task environment.

As a contribution of the protocol study, the proposed conceptual operations on the two workspaces and the coding scheme developed together provide opportunities for the characterisation of anticipatory and preparatory behaviour, which can be used in future field and laboratory studies on behaviour observed in a complex environment.

Compared with the direct observation study, the protocol study forced the analysis to be done at a comparatively more detailed level (episode by episode). Through the protocol analysis, the major findings of the direct observation study received support from the detailed patterns of behaviour revealed. These patterns exposed not only the ways in which anaesthesiologists prepared, but also the manner in which the preparation influenced the subsequent behaviour in execution of actions and in responses to the on-going events in the environment. The protocol analysis thus gave confidence to the central finding of the observation study that an important class of problem solving activities are anticipatory and preparatory and they are not driven directly by the events in the environment. At the same time, the collected protocols enable the readers to access the raw data of the study, and make it possible for future independent analysis.

### 7.2.3 Are preparation and anticipation important?

The purpose of the PRP study was to seek evidence that supported the claim that anticipatory and preparatory activities are an important class of problem solving activities in the domain of anaesthesiology, and they are critical to skills in anaesthesiology. This claim is the central finding of the direct observation study and the basis for the protocol study. It also enables the findings in the field study to have practical value in training and aiding, two of the ultimate goals of studying behaviour in the discipline of human factors.

The PRP study, through charting the foci of discussions of previous cases, shows clearly the importance, from the viewpoint of anaesthesiologists, of being sensitive to precursors of problems and being prepared for anticipated events. It also shows the importance of being able to respond effectively to unanticipated events. While the PRP study provides support to the claim on the central theme of the field study, it also demonstrates some of the limitations of field studies, for example, in the scope of problem solving situations.

* * *

The three phases in the field study (the direct observation study, the protocol study, and the PRP study) have revealed a large number of interesting patterns of problem solving activities in anaesthesia. In essence, these findings are a set of *hypotheses* about the answers to the research question of "what problems are solved by practitioners in naturalistic settings?" The discussions above on the epistemology of the field study make it clear that, even though the current field study lacks conventional rigorous and comprehensive validation of its final results, it contributes to the understanding of preparatory behaviour and the role of anticipation and preparation in successfully interacting with a complex task environment. In terms of methodology, the field study provides a set of concepts and a framework useful for understanding and analysing behavioural phenomena when observing proficient workers in an actual work environment. The field study also revealed evidence that supports the claim that an important class of problems to be solved is to anticipate and prepare.

However, in the current study, the protocols were basically analysed by one person, and no strict quantitative analyses were done. Further studies (either in the field or in the laboratory) and analysis are required to provide more support to the findings and the interpretation of the protocol data.

## 7.3 Feedforward, anticipation, preparation, and prevention

Feedforward and prevention are two concepts very closely related to anticipation and preparation. This section discusses the relationship between these concepts.

Feedforward control is a well defined term in the domain of control engineering and motor control. For example, Schmidt (1988) gives a rather generic description of feedforward control:

> ...feedforward is information sent forward to ready some part of the system in some way. It can (a) ready the effector level for the arrival of future commands for action or (b) ready (or preset) reference systems to "expect" a certain signal. All of these actions can be seen as anticipatory or preparatory, as they occur prior to the commands for the action and all prior to the feedback from the action itself [p. 146].

According to this definition, preparation of the physical and mental workspace are just two special kinds of behaviour that uses feedforward information. Before an event happens, the anaesthesiologist usually has some anticipation of what to expect and has begun to prepare what to do if that event actually happens. The preparation can take the form of constructing a new response plan, modifying an existing one, or rehearsing and substantiating the general procedures, as noted by Rasmussen *et al.* (Rasmussen *et al.*, 1989, p.52): "At the rule-based level, the conscious attention may run ahead of the skilled performance, preparing rules for coming requirements."

However, two forms of feedforward control have to be differentiated when studying human behaviour, and they differ in the way in which the feedforward information is used. In one form of feedforward control, the anaesthesiologist uses feedforward information to control the status of the patient. This form of feedforward control is sometimes called "predictive control" (Bainbridge, 1974). Even though not central to this thesis, this type of feedforward control strategy was widely used by the subjects. Examples can be found in the protocols included in the appendices (*e.g.*, Episode Wp-47 on page 195, Episode Wp-50 on page 196, Episode Lob-45 on page 265, Episode Sal-29 on page 276, Episode Val-91 on page 235, and Episode Val-91 on page 239). In most instances, and also in the most obvious form of feedforward control, the subject regulated the patient's blood pressure by anticipating future system inputs (*i.e.*, the surgeon's actions to the patient). In her study of melting-shop operators, Bainbridge (1974, see also Figure 2.1) has captured quite elegantly the basic properties of feedforward control of this form.

The other form of feedforward control is the central thesis of the present field study, that is, the anaesthesiologist prepares mentally and physically for future actions. The feedforward information is used not to control the system's (*i.e.*, the patient's) status, but to "ready" the anaesthesiologist. This thesis uses the terms "anticipation" and "preparation" to specifically indicate the latter types of feedforward control.

Another potentially confusing term is "prevention." One of the consequences of anticipation is to prevent stressing or troublesome situations from occurring. One has to be prepared for a troublesome situation even after effort has been made to avoid the situation. An example is shown in Figure 5.5, in which case attempts were made to prevent the problem of hypertension from arising before the contingency plans were invoked.

There is a temptation to trivialise the term "prevention" in medical practice. Certainly everything that an anaesthesiologist does can be viewed as some form of prevention of undesired outcome. However, the preventive behaviours found in this thesis are much more extensive than simply avoiding undesired patient status and outcomes. Specifically, at least three types of preventive strategies can be identified:

- Preventing patient status from becoming dangerous
- Preventing over-loading situations on the part of the anaesthesiologist
- Preventing situations where no satisfactory solutions are known to exist.

Similar to the cliché in aviation that expert pilots will avoid situations where they have to exercise their superior skills, anaesthesiologists also have the meta-knowledge about whether their skills and physical resources are adequate for various crisis situations, and they too avoid them accordingly.

## 7.4 Anticipation and preparation in an uncertain environment

The ability to anticipate future events is, almost by definition, the key component in anticipatory and preparatory activities. Being in a highly dynamic environment (OR) and dealing with a partially known system (the human physiology), anaesthesiologists seem to have a "super-human" capability to anticipate, apparently, efficiently. They seem to know by "instinct" where the trouble spots are and what needs to be done. This section examines two factors that could de-mystify the anaesthesiologist's ability to anticipate.

### 7.4.1 Textbook examples of precues

Textbooks in anaesthesiology actually provide anaesthesiologists with many examples of associating precues with likely problems. The followings are two examples from the book "*Understanding Anaesthesia*" (Carrie, 1982).

**Example I:**

> Many of the patients presenting for lung resection are severely incapacitated and breathless but nevertheless tolerate operations reasonably well. By the nature of the disease they are often heavy smokers and may already have a limited exercise tolerance [p. 320].

The association of a surgical procedure (lung resection) with the patient's medical status (often heavy smokers and having a limited exercise tolerance) gives anaesthesiologists the ability to anticipate these two characteristics of the patient. Thus the information seeking activities are likely to be marked by attempts to confirm anticipations and associated problems with these two characteristics.

**Example II:**

> Other indices of inadequate oxygenation during one-lung anaesthesia are a rising pulse rate or blood pressure occurring soon after the lung has been collapsed [p. 321].

Without this knowledge, the anaesthesiologist would have to constantly sample all channels of information sources and assess all aspects of the patient's status (including oxygenation). This knowledge allows the anaesthesiologist to expect signs of inadequate oxygenation. After the procedure of a lung being collapsed during the surgery, the attention can be focused on the pulse rate and blood pressure if oxygenation is of concern. The anticipation thus limits the problem space and scope of data searching.

### 7.4.2 Direct association

Another factor that could contribute to efficiency in anticipation and preparation is direct association.

One obvious method for one to anticipate is through mental simulation, in which trouble spots and the need for preparation can be detected. However, through training and practice, the frequency and the nature of mental simulation are likely to change to improve the efficiency. Consider Figure 7.1. In this example, the protocol data showed that the anaesthesiologist detected the need for a stretcher, but did not give any indication of how. In retrospect, he described that after he recalled his last bone marrow harvest operation, he visualised the position of the patient (prone position), which led him to detect the need for a stretcher. The top block of Figure 7.1 shows some other possible routes that one can follow to detect the material need for a contingency plan (*i.e.*, re-intubation after accidental displacement of ETT).

## 7.5 Related studies

An increasing number of studies have been done to investigate the so-called strategic behaviour involved in planning (*e.g.*, Johannsen & Rouse, 1983; Moray *et al.*, 1991), partly due to the rising level of automation (*e.g.*, Sanderson, 1989), and partly due to the recognition that human operators usually anticipate future events and coordinate their current activities with those in the future (*e.g.*, Raby & Wickens, 1990; Redding & Cannon, 1992). Those studies are related to the current field study; however, most of them only examined the planning part of the behaviour, not the action part.

The study on pilots done by Amalberti and Deblon (1992, see a review in this thesis on page 18) in many ways resembles the current study, and their findings are very similar, too.

Some of the findings in the present study are related also to research on naturalistic decision making. For example, Klein (1989) found that mental simulation was a primary means for the practitioner to examine an option. In the current study, in order to detect the need for preparation, the anaesthesiologist has to in some way examine anticipated situations and response plans. Mental simulation is a plausible way of doing that. Direct association (see the example in Figure 7.1) that appear to be used by the anaesthesiologist may be a partial answer to one of the twenty questions in the research of naturalistic decision making posed by Klein (1993b, p. 395): "As people become more experienced how do their mental simulations change?"

## 7.6 Concluding remarks

The current field study can be viewed as an experiment in seeking recurring patterns in the diverse trajectories of activities observed in field conditions. At the spatial-temporal-linguistic level, the activities may seem random and without meaningful patterns. However, through abstraction and conceptualisation, structures began to emerge. The preparatory framework and the accompanying concepts, the physical and mental workspace, have been vital in the abstraction and conceptualisation process. The attempt to understand the preparatory activities has led to some general understanding of the question of how the practitioner *actively* organises mental and physical activities in a complex, dynamic work environment.

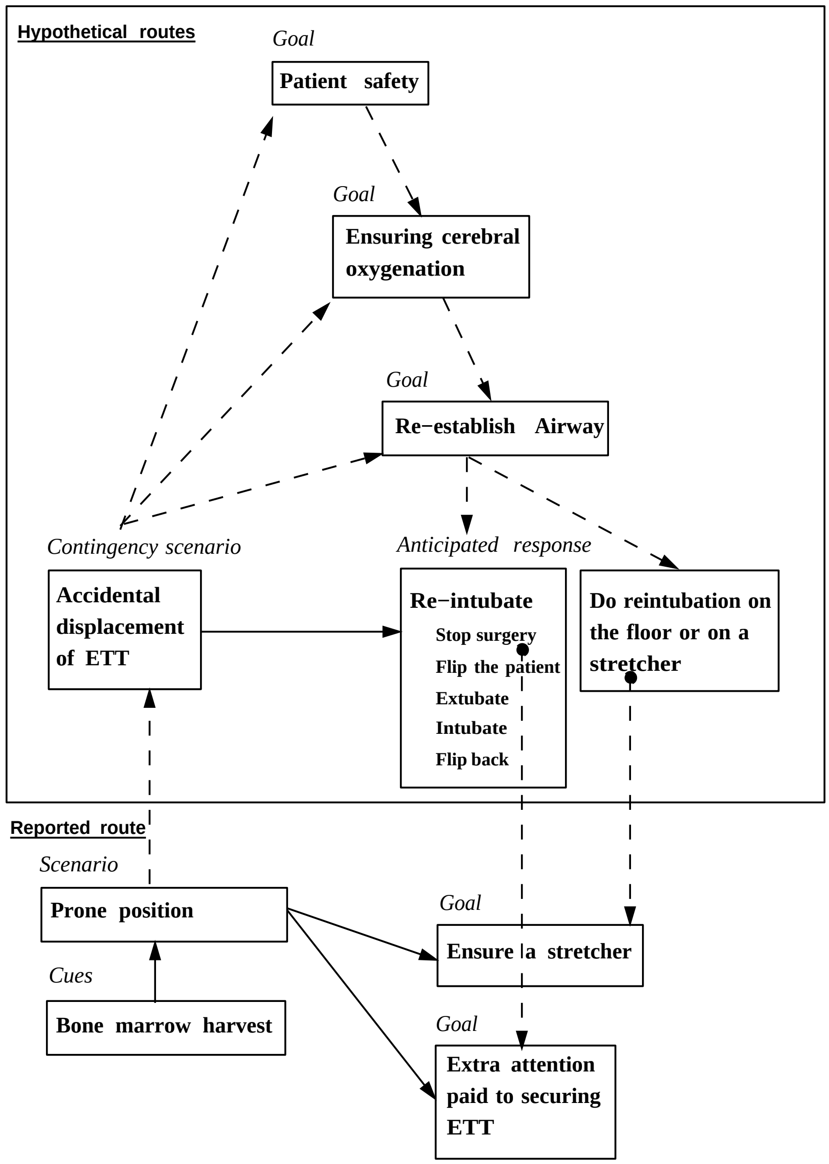



Figure 7.1: Direct association in anticipation and preparation. This example (from the case reported in Appendix L) demonstrates different levels of mental simulation in detecting the need for preparation. The items in the bottom outside the big block were reflected in the protocol data (see Appendix L). The items inside the big block are hypothetical routes of mental simulations that could lead to detection of a similar need for preparation. For an experienced anaesthesiologist, the mental simulation is likely to be brief and through direct associations. "Prone position" is the type of surgical positions in which the patient is placed face down and the surgeon operates on the back of the patient.

# 8 Understanding Preparatory Behaviour: Issues and Challenges

The study on problem solving activities described in this Part II is largely empirical, collecting behavioural patterns in much the same manner as that of a botanist collecting species of plants in nature. The preparatory framework provided a summary of eight classes of problem solving activities that could be characterised as preparatory (see Fig. 4.5). The framework functioned as a guide for the protocol study, which analysed relatively detailed flows of events and activities through the protocol data. The present chapter reviews a few key issues in understanding the preparatory behaviour, and raises the question of how to model this preparatory behaviour in the context of managing complex systems. It also functions as an introduction to Part III of the dissertation.

The field study illustrates a central theme: a significant portion of the anaesthesiologist's activities are oriented towards *anticipated* problems. He or she may execute a "mental checklist" but still need the feedback information from the environment, and thus gives the impression that her or his activities are driven directly by events in the environment. When tracing the cause of mental and physical activities, one would find that, while some of the activities were triggered by easily identifiable environmental events, the causes of others were not so obvious. For those activities in the former category, it is often the case that, although the activity was triggered by some environmental events, the anticipation of and preparation for those activities had begun much earlier than the triggering events. In other words, the subject's activities and current environment events were not so closely coupled. The subject responds not only to the events in the environment, but also to anticipated events.

Similar patterns have been noted in other studies of proficient workers in actual work settings. For example, Beishon (1974) found that the behaviour of process controllers seemed to be controlled by some "master executives," and it was often hard to correspond observed actions to any immediate stimulus or events.

The difficulties encountered in studying behavioural streams can be illustrated through the issue of unit of analysis, as depicted by Figure 8.1. In that figure, an example is shown of analysing the observed behavior at three different hierarchical layers. Note that the larger the unit, the more has to be inferred about mental activities, and the more mental constructs one has to introduce. Behavioural streams observed in work settings extend over time, and can be analysed in different units and at different levels. To the student of human behaviour, however, the stimulus-response paradigm has historically been a favourite one. It views a human being as if he or she were some sort of a mechanical device, with the task of inquiry limited to observing correlations between stimuli and responses, *i.e.*, studying behaviour *within* the basic unit: the event → mental process → response (EPR) cycle.

However, there are some serious consequences associated with choosing such an event-driven, passive response cycle. For example, the expertise studied will concern only how

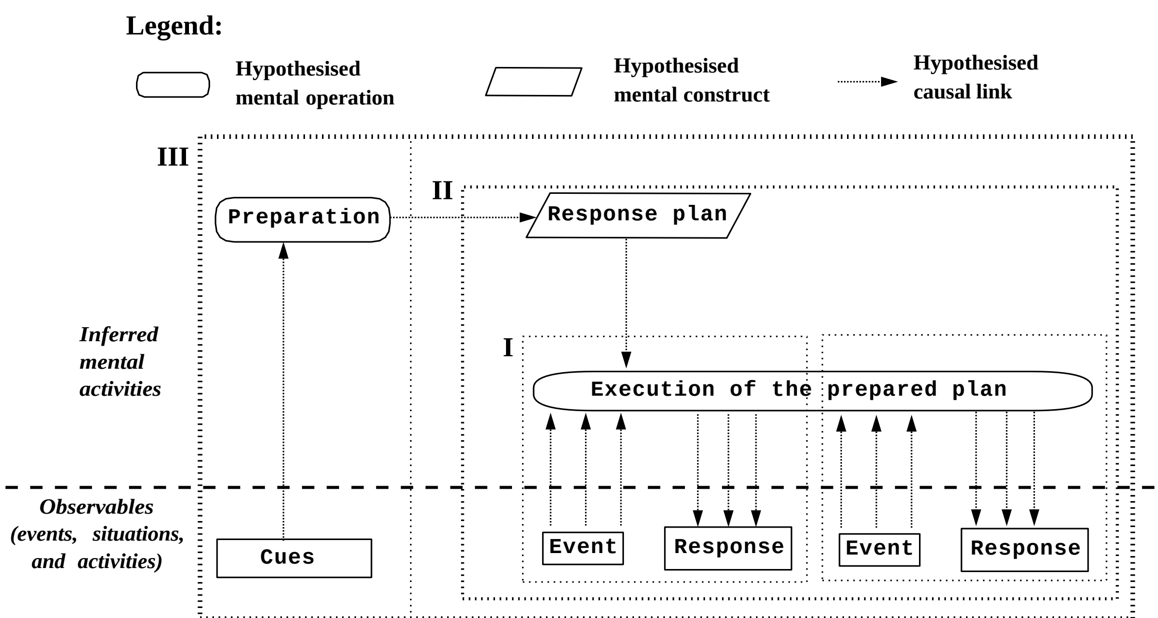



Figure 8.1: The issue of unit of analysis. Observed behaviour can be analysed in different units at different levels. In unit I (the box with the label "I"), the behavioural stream is segmented into event-response pairs (EPR cycles), and the structure in the stream is no more than linear, sequential relationships. In unit II, more than one (two shown here) EPR cycles are considered, and they are organised through a conceptual, mental construct, or "plan," which governs individual EPR cycles. In unit III, an even richer structure is revealed. Activities isolated in time are related within this unit. Responses to events (in the environment) are no longer part of a passive, event-driven process, but involve anticipation and preparation.

to respond to a problematic situation, instead of how to prevent it. The cognitive load associated with coordinating efforts beyond the basic EPR cycle, or in maintaining an action once it is taken, is hardly considered. Mental workload studies that confine subjects to single EPR cycles, for example, do not typically reveal strategies in workload scheduling (which has recently been a focus of study in, for example, Redding & Cannon, 1992; Raby & Wickens, 1990; Hart & Wickens, 1990).

The inadequacy of limiting the scope of inquiry to EPR cycles is even more acute when we deal with behavioural phenomena observed from proficient practitioners in naturalistic settings. This inadequacy can be viewed from the two following perspectives:

- *Experience.* With the accumulation of experience, the ability to predict the future increases. Therefore the activities observed (or inferred) are in response not only to immediate stimuli in the environment, but also to anticipation of future situations.
- *Prior processing.* Due to anticipation, the preparation of responses often starts prior to the actual observation of events. This factor is made more prominent by the fact that anaesthesiologists, for example, usually have the chance of visiting the patient, checking medical records, and preparing responses to expected stimulus or events beforehand.

Anticipatory and preparatory activities certainly pose challenges for the comprehension of observed behavioural phenomenon. They force us to seek answers to the question of how proficient practitioners make use of their knowledge about the task domain and organise their activities to cope with work environments such as the OR.

The next part (Part III) will attempt to built a model of planning to explain preparatory behaviour in general and the findings in this field study in particular.