THE PATIENT FLOW MODEL:
A CLINICALLY-FOCUSSED, RESOURCE-BASED APPROACH TO DATA MODELLING

by

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A thesis
presented to the University of Waterloo
in fulfilment of the
thesis requirement for the degree of
Doctor of Philosophy
in
Management Sciences

Waterloo, Ontario, Canada 1997

0-612-30629-1

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Abstract

The Patient Flow Model is a resource-based approach to the modelling of clinical flows in healthcare settings. Consisting of a conceptual design, a network diagramming convention, and a set of rules used to operationalize the model using mathematical programming techniques, the Patient Flow Model allows decision-makers to explore the complex interactions that exist between *how healthcare is provided* and the *resources needed to provide that care*.

The Patient Flow Model is based on the premise that the relationship between a patient and a healthcare facility can be explained using a paradigm that considers patients to exist in a variety of *states*, each of which is a deciding factor with respect to determining what *treatment(s)* a patient will receive, and that the treatment received by a patient dictates what *resources* the hospital will use in order to provide care. The design of the model allows decision-makers to employ a number of approaches to problem solution including optimization, simulation and replication. The model embraces an activity-based approach to cost determination.

Comprehensive functional specifications for the model are developed, a methodology for the creation of clinical and resource networks is described, and demonstration models are illustrated.

Acknowledgements

Each of us is inspired by many skilled teachers during our education. Their wisdom brings clarity to even the most abstract concept, and their sage advice proves invaluable time after time. I feel particularly grateful to have benefited from the mentoring of two such teachers. Some ten years ago, Dr. Howard Armitage had the courage to invite into his office an undergraduate student who was interested in doing a research project, but was not sure about what to study or where to start. On that day, Howard planted a small seed – a seed that would grow from undergraduate student to university professor. For his guidance and constant encouragement, I will be forever grateful. I also owe a debt of gratitude to Dr. John B. Moore who took the seed planted by Howard and nourished it until it grew into a dissertation. "J.B.'s" ability to entertain the same question three and four times, and greet each with the same patient understanding is a trait I admired. No matter how dim the light at the end of the tunnel seemed, I could always count on J.B. to recharge my batteries and redirect me in the right direction. I am honoured to have been one of his students.

I appreciate the effort extended by my cross-departmental committee. To the accountants who waded through unfamiliar information system concepts, and to the systems experts who were sometimes perplexed by the machinations of accounting – my thanks for your perseverance. I want to particularly thank Dr. Jochen Moehr for the interest he took in my work.

And I am indebted to my wife, whose support and encouragement throughout my education made this effort possible.

For my parents who fostered my love of learning
and encouraged me to attain my dreams.

And to Brennan and Corey for whom I promise
to do the same.

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Chapter 1
Research Overview

"In attempting to arrive at the truth, I have applied everywhere for information. In scarcely an instance have I been able to obtain hospital records fit for any purpose of comparison. If they could be obtained, they would enable us to decide many questions. They would show subscribers how their money was spent, what amount of good was done with it, or whether the money was not doing mischief rather than good."

Florence Nightingale
Notes on Hospitals, 1873

1.1 Introduction

Florence Nightingale penned these words more than a century ago. And while great strides have been made in the development of comprehensive hospital information systems, her call for a better understanding of how money was spent and what good was done with it is a cry still heard today. The research reported in this document helps answer this call by describing a project undertaken to conceive, define, develop, and implement, a clinically-focussed, resource-based approach to data modelling for use in healthcare settings. The Patient Flow Model is the result of this research.

The Patient Flow Model is an approach to data modelling that allows decision makers to simultaneously explore the complex interactions that exist between *how healthcare is provided* and the *resources needed to provide care* in a hospital. Information generated by Patient Flow Models combines insights into clinical practice with powerful financial reporting capabilities. The model's ability to link the process of providing care with the process of consuming resources allows the Patient Flow Model to support the linkage that exists between the science of medicine and the social science of managerial accounting.

Refinement of the Patient Flow Model during the tenure of this research resulted in a modelling tool that has a conceptually simple foundation and yet retains its ability to address complex problems. This report outlines the current structure of the model and documents the methodology used to explore the model's application in real-world settings.

This chapter begins the discussion of the Patient Flow Model by introducing the following:

- the motivation for developing a tool such as the Patient Flow Model for use in health care settings;
- an explanation of the Patient Flow Model's underlying conceptual foundation;
- the characteristics of the Patient Flow Model that make it an attractive modelling tool; and
- types of problems the Patient Flow Model is well suited to address.

The chapter concludes by defining the scope of the research outlined in this document.

1.2 Motivation

Healthcare spending represents a significant expenditure in developed countries throughout the world. In Canada alone, healthcare spending is forecast to be $76.6 billion in 1997 or 9.2% of the country's Gross Domestic Product (GDP). Only the U.S., Germany and France have higher health-to-GDP ratios [CIHI, 1997b]. Historical averages show that approximately 40% of healthcare spending occurs in institutional settings such as hospitals[1] [Health Canada, 1994].

With costs rising faster than the tax base from which support must be drawn, and with a desire by all levels of government to deliver balanced budgets, funding allocations to healthcare have come under careful examination. This examination often results in funding reductions and/or reallocations of the healthcare spending envelope. Significant restructuring has already occurred in some provinces [Saskatchewan, 1996; Alberta, 1996]. Ontario is following suit. (See HSRC [1997a; 1997b; 1997c].) The pressure is squarely on healthcare providers to find ways of delivering effective and efficient services in an environment of decreasing financial resources [Evans, 1993].

Searching for ways to accomplish this goal is a challenging exercise. This is because while control over case mix and clinical decisions lie with physicians, the impact of those decisions is the responsibility of hospital management. Although new technologies have brought improvements in productivity, these improvements are often accompanied by costly treatment protocols which require increased testing, equipment, space and nursing [Goldman et. al, 1991; Hadorn, 1991]. Providing one patient with a liver transplant was thought in the late 1980s to cost over $182,000 while even a

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1 The remaining 60% represents spending on physician fees, prescribed and non-prescribed drugs and fees paid to other medical professionals. All numbers include spending by federal, provincial and local governments, and worker's compensation boards and the private sector.

routine hip replacement procedure can cost $6,000 [Banta, 1987]. By the late 1990s, prosthesis costs alone can exceed $2,500 per patient [Cheung et al., forthcoming]. At the margin, a dilemma is faced by a hospital having to choose between caring for one transplant patient, or providing thirty patients with new hips.

In order to make informed decisions, physicians and healthcare mangers need access to data on the cost of providing care. Few Canadian physicians or hospital managers have access to either the data or the tools needed to make these decisions. Information systems able to calculate costs at the patient level are complex and expensive. Of the over 1000 hospitals in Canada, under 100 have comprehensive patient specific costing systems [CIHI, 1995]. While sophisticated computerized financial information systems are common in hospital environments, these systems generally have a strong record-keeping (as opposed to planning) focus [CIHI, 1995].

Physicians and hospital managers alike are looking for better ways to collect, interpret and compare cost and performance information [Baptist and Stein, 1987; Evans, 1993]. They also need tools enabling them to explore how they can obtain the most benefit from the available (and often constrained) physical plant, labour and supply resources present in their hospitals.

The need to develop a means to track, monitor and explore financial and performance data regarding hospital activity is evident in the investment of time and money currently being made by every Canadian province to establish standardized, comprehensive financial information systems in their acute care facilities [CIHI, 1997b]. As hospital administrators and physician managers struggle to find ways to change practice patterns to meet cost saving objectives established by restructuring commissions (see for example HSRC [1997b]), access to planning tools able to simulate possible future states and better understand current states becomes critical [Shortell et al., 1993; Hobbs and Hawker, 1995].

The Patient Flow Model is such a tool. The Patient Flow Model offers an elegant way in which to represent, in a unified manner, the interaction between clinical practice and resource utilization. By seamlessly integrating clinical and financial data, and by adding the ability to use powerful mathematical routines to explore the data, the Patient Flow Model provides hospital administrators and physician managers with a useful decision-support aid that fills an important need.

1.3 The Patient Flow Model

The Patient Flow Model is based on the premise that the interaction between a patient and a healthcare institution (such as a hospital) can be explained using a paradigm that considers patients to exist in a variety of *states*[2], each of which is a determining factor with respect to deciding what *treatment(s)* a patient will receive, and that the treatment received by a patient dictates what *resources* the hospital will need to use in order to provide care. That is, the Patient Flow Model explains the relationships that exist between patients, their condition (*States*), the care they receive (*Treatments*), and the material, labour and equipment available in the hospital (*Resources*).

While there is usually a sharp distinction between the domain of clinical practice (which is largely concerned with *how* care is provided) and the realm of financial management (which is usually concerned with the *cost* of providing care), the Patient Flow Model integrates these two

[2] A patient's *State* reflects an attribute of the patient's physical condition. For example, a patient might exist in a *State* of "hypoglycemic."

worlds. In doing so, the Patient Flow Model provides both clinical providers (such as doctors, therapists, nurses, etc.) and financial administrators (such as accountants, executives, and policy planners) with a powerful decision-support tool.

1.3.1 Characteristics of the Patient Flow Model

The Patient Flow Model derives its strength from four key characteristics – *simplicity*, *flexibility*, *usability* and *power*.

The *simplicity* of the Patient Flow Model comes from the model's ability to represent the complex world of the modern health care facility using only a small number of entities. The Patient Flow Model provides a simple way to model and reflect the real world. This simplicity allows decision-makers to quickly grasp the process of designing new models and using existing models.

The *power* of the Patient Flow Model comes from the model's explicit recognition of the relationships that exist between patients, the treatments they receive and the resources needed to provide care. The model has been specifically designed to permit the use of mathematical programming techniques[3] to identify situations that satisfy the nature of these relationships. Objective functions as simple as ensuring that the number of patients admitted never exceeds the number of beds available, or as complex as identifying a series of treatments that will reduce the length of stay by two days without compromising the patient's prognosis are easy to explore.

[3] The Patient Flow Model uses linear programming methods. Extensions to the model will allow the use of non-linear programming methods.

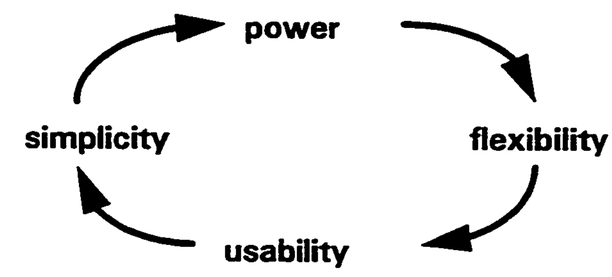

Figure 1.3A
Characteristics of the Patient Flow Model

Because the Patient Flow Model has a strong conceptual foundation, the model can be described independent of a specific software tool. This allows the Patient Flow Model concept to be implemented using any software application that can accommodate the required data storage, information presentation and mathematical processing capabilities. This brings considerable *flexibility* to the Patient Flow Model. And finally, the model's use of a highly visual method to represent the real world brings *usability*. Decision-makers do not require special information systems training or specialized mathematical expertise in order to use the model.

1.3.2 Examples of Information Generated by the Patient Flow Model

The Patient Flow Model generates a wide variety of operational and financial information. Some of the operational questions the model can address include;

- determining the effect on patient throughput of adding (or removing) staff on a ward;
- examining whether a new treatment protocol will affect the average length of patient stay;
- identifying resource shortages that will limit the ability to handle an expected level of patient encounters, and

- developing resource requirement plans (as might be seen in Material Requirements Planning systems used in manufacturing environments)

Examples of financial issues with which the model can provide assistance include:

- determining the cost of treating particular groups of patients;
- evaluating the financial impact of acquiring new diagnostic tools; and,
- creating budget and planning documents.

The Patient Flow Model can also generate a wide variety of financial and performance indicators. A selection of these indicators include:

- resource utilization (e.g., surgical suite use as a percent of availability);
- cost per treatment provided;
- cost per patient;
- average length of patient stay;
- itemized resource consumption costs (e.g., total cost of inpatient nursing);
- summarized departmental costs (e.g., cost of operating Clinical Pharmacy); and
- cost of unused capacity (costs incurred acquiring resources that were not fully utilized).

1.3.3 Generating Other Information Using the Patient Flow Model

Section 1.3.2 presents a small sample of information decision-makers can obtain using a Patient Flow Model. The Patient Flow Model is able to generate a wealth of information regarding clinical activities and the resources used to support these activities. Because the storage and representation of data by the Patient Flow Model is completely independent of the reporting tool used to convey information to users, decision-makers are free to choose a reporting tool able to portray information in a wide variety of formats.

In addition to allowing users to generate customized Patient Flow Model reports, the Patient Flow Model can also be tailored to meet the needs of operational, tactical and/or strategic level managers [after Anthony, 1965]. This is accomplished by varying the degree of granularity used in the design of the model. For example, departmental managers might have an interest in modelling resources and patient flows at the micro-level. This is accomplished by using a narrow definition of what constitutes a Treatment. Patient Flow Models designed for use by regional health administrators are able to use the same model constructs to develop macro-level models that consolidate the operations of more than one hospital by broadening the definition of a Treatment.

1.3.4 The Patient Flow Model is More than an Optimization Tool

The previous two sub-sections illustrate the flexibility of the Patient Flow Model with respect to generating output. Much of this flexibility is derived from the power of the mathematical programming routines used to solve Patient Flow Models. The field of mathematical programming is well developed and commercial tools are now available that are able to solve real-world sized problems. Because the Patient Flow Model has been designed so that it maps directly into problem definition structures used in mathematical programming, the Patient Flow Model can be used in a variety of ways. These include:

- ***simulation*** - exploring a future state based on a "what-if" scenario;
- ***replication*** - reproducing a prior state to gain insights into previous events;

- ***feasibility*** - determining if it is possible for a desired future state to exist;
- ***optimization*** - identifying the "best" future state given a particular objective function; and
- ***approximation*** - identifying a "good" future state using heuristics.

While the Patient Flow Model's ability to find optimal solutions given a particular objective function is a powerful feature of the model, this list demonstrates how optimization represents only one of five possible ways in which the Patient Flow Model can be used. Users can exploit the features of the Patient Flow Model in whatever mode best matches their decision-making requirements.

1.4 Scope of the Research

This research develops an approach to data modelling tailored specifically for healthcare settings. The project then develops the formal specifications needed to move the model from a conceptual level to an operational level. Finally, the research shows how the model can be used in healthcare settings.

Within this framework, the research project reported in this document achieves the following objectives:

a) the research defines the structure of the Patient Flow Model in a manner that allows the model to capture both operational and financial information regarding patient encounters within hospital settings;

b) the research develops a visual modelling technique used to represent the problem domain of interest to the decision-maker;

c) the research develops a formal mathematical programming model that can be used to identify optimal patient flows and resource utilization; and

d) the research demonstrates the application of the model in actual healthcare settings.

A number of possible enhancements to the Patient Flow Model lie outside the scope of the research project. These enhancements are discussed in Chapter Six.

1.5 Contribution

The research chronicled in this report makes three important contributions. These contributions are summarized below.

- The research introduces a method for data modelling that is unique in its ability to portray the complex interaction between clinical practice and the process by which resources are used to provide patient care.

- The research provides Canadian hospitals with the specifications for a computerized tool able to support an activity-driven approach to costing that can complement the conventional two-stage allocation process currently used.

- The research demonstrates how accepted theory from three separate disciplines can be merged to address an unmet need.

These contributions are achieved by developing the formal specifications for an approach to data modelling (the Patient Flow Model) that is clinically-focussed and resource-based. The following steps were taken to develop the Patient Flow Model:

1. identification of an appropriate modelling approach (Netform modelling was chosen.)

2. development of a schematic representation (A format for the portrayal of both clinical and resource networks was developed.)

3. a development methodology was created for the creation of Patient Flow Models

4. prototype demonstration models were built reflecting three levels of complexity (the last being a real-world healthcare setting)

1.6 Organization of this Report

The report is organized as follows. Chapter Two reviews three streams of literature and shows how the Patient Flow Model is a logical convergence of practices drawn from multiple disciplines. Chapter Three outlines the model's functional specifications and addresses issues related to the operational dimension of the model. The operational dimension of the model is largely concerned with clinical issues related to *what treatments* are provided to *which patients*.

Chapter Four extends this discussion by focusing attention on the model's financial dimension. The financial dimension of the model focuses attention on issues related to the *use and cost of the resources* employed to provide care to patients. Chapter Five moves the theoretical discussions in Chapters Three and Four into the applied domain. A methodology is introduced in Chapter Five for the development of Patient Flow Models, and the results of a live implementation are discussed. Chapter Six concludes the study by summarizing findings from the research together with a discussion of how the model has been designed to accommodate extensions which will allow additional functionality to be incorporated at a later date.

Chapter 2
Examining the Related Literature

2.0 Overview

The design and structure of the Patient Flow Model draws on three areas of literature. Operations research work in the area of modelling, network flows and linear programming provide a foundation upon which the diagramming and optimisation techniques are based. The accounting literature provides support and guidance for the mechanism used to attach costs to specific patient groups, and the healthcare literature guides the application of the model and motivates the project.

This chapter reviews the literature in each of these three areas. Previous work in the area of modelling patient flows in healthcare settings is also examined and demonstrates how the Patient Flow Model is a logical extension of healthcare modelling applications developed to date.

2.1 Literature on Network Modelling

This section provides an overview of the development and application of network modelling techniques. The section begins by demonstrating why network modelling is an appropriate strategy to choose to operationalise a model such as the Patient Flow Model. It is seen that while early research provided the conceptual foundation upon which network modelling could be developed as a discipline, the development of robust applications had to await the advent of high speed computers. Advantages of using a particular variant of network modelling called *netform modelling*[1] are discussed, and the suitability of the technique for use with the Patient Flow Model is shown.

2.1.1 Choosing a Network Approach for the Patient Flow Model

The underlying premise of the Patient Flow Model is that the relationship between a patient and a healthcare facility can be explained using a paradigm that considers patients to exist in a variety of states, each of which is a deciding factor with respect to determining what treatment(s) a patient will receive, and that the treatment received by a patient determines what resources the hospital will use in order to provide care.

The first part of this paradigm (i.e., that patients move through an alternating sequence of states and treatments) is consistent with the conceptual framework of network models wherein a network is considered to consist of a collection of points (called nodes) which are connected by

[1] The term netform stands for network flow-based (or network related) formulation. Netforms are characterized by the use of diagrams that have emerged, by progressive elaboration, from those used traditionally in network flow and graph theory [Glover, Klingman and Phillips, 1992, p1].

directed lines (called arcs) [Camm and Evans, 1996]. Thus, the focus of Section 2.1 is on the development of the network approach to decision modelling. A wide variety of problems can be addressed using networks. Section 2.1.2 discusses early developments in the field of mathematical modelling and Section 2.1.3 extends this discussion by illustrating a number of practical applications for the network approach. A discussion of medical applications using network models is reserved until Section 2.2.

2.1.2 Early Work

The first application of network modelling as a problem definition and solution technique is generally attributed to Kantorovich [1939]. Kantorovich was an economist responsible for developing state production plans in World War II Russia. Kantorovich reasoned that factory production could be maximised if he could develop a method of optimally assigning production levels to different factories after taking into account the markets served by each factory. Almost simultaneously, and unknown to Kantorovich, Koopmans [1947] faced a similar problem. Koopmans needed to arrange for the movement of naval staff, supply and equipment between U.S. military bases, taking into account the needs of each base. Koopmans solution approach (like Kantorovich's) involved the development of a visual problem representation technique accompanied by an algorithmic solution method. Koopmans and Kantorovich both used what is known today as linear network optimisation techniques to address the problems they faced. Some thirty years later, the significant contribution that these two scientists made to the development of mathematical modelling tools would be recognised with the awarding of Nobel prizes.

The utility of the network approach to problem specification and solution can be seen in the thousands of papers that have subsequently been written in this area. The strength of this problem solving approach is largely due to the fact that despite their simplicity, linear network problems embody a rich structure of both a continuous and combinatorial character [Bertsekas, 1991, p. ix].

Koopmans' work was evidence of a new thrust in operations research and management science research during the early 1940s. World War II saw a refocussing of problem solution techniques from the theoretical to the applied. During this period, scientists from both the operations research and the management science domains collaborated (some authors suggest for the first time) to develop the algorithms needed to support the radar technology being developed to defend Great Britain [Glover, Klingman and Phillips, 1992].

Two other significant developments would occur during the 1940s. The first was the introduction of the digital computer. The power of the digital computer would allow later mathematicians to explore problems of a magnitude not possible using manual or mechanically assisted methods. The second development was the work of Dantzig [1951] who provided the first robust algorithmic approach to solving linear network optimisation problems in the form of the simplex method. Although the simplex method represented a breakthrough in algorithmic solution methods, as recent as 1970, problems of real world complexity could still not be addressed because the computing power necessary to solve large networks still did not exist. (Networks of about 600 nodes with 2000 arcs strained the available computing power [Glover, Klingman and Phillips, 1992, p. ix].) Golden and Magnanti [1977] chronicle the work during this period. They identify over 750 articles dealing with applications and developments in linear network optimisation stemming from Kantorovich's [1939] and Koopman's [1947] seminal work.

2.1.3 Network Models

The realisation that many problems in the management science and operations research domain could be addressed using network models began in the 1950s. Network models provided a way to recast problems that would otherwise be represented using only mathematical notation by using a visual framework consisting of nodes (representing decision points) and arcs connecting nodes (representing paths to subsequent decision nodes.) While the groundwork for the formulation of problems using a network model approach was laid in the 1950s and 1960s, advances in determining model solutions would await the development of high speed digital computers in the late 1960s.

A number of types of problems amenable to solution using the network approach became apparent. Significant development contributions to transportation problems (in which the goal is to move goods from a set of shippers to a set of receivers) were made by Flood [1953], Ford and Fulkerson [1956] and Dennis [1958]. Motzkin [1957], Munkres [1957], and Ford and Fulkerson [1962] demonstrated network applications to bipartite problems (such as assigning people to tasks), while Dantzig [1956] and Ford and Fulkerson [1957] addressed maximum flow problems. Enhancement of basic network models, such as the trans-shipment problem (which examines how to best move products through a series of warehouses on their way to a destination) would also prove to be amenable to a network solution approach [Orden, 1956; Charnes and Cooper, 1961]. Network modelling is now well accepted technique for addressing a wide variety of operation research problems. (See for example, Ahuja, Magnati and Orlin [1993]; Murty [1992].)

2.1.4 Representative Examples of Applications

There are many examples of successful applications of network models to solve real world problems. A car manufacturer uses network modelling to determine how many of a particular car model to produce at each factory and then to ship to various cities [Glover and Klingman, 1977]. Application in financial markets is demonstrated by Rudd and Schroeder [1982] using a model that calculates the minimum deposit or margin that a broker must obtain from an investor in option trading situations. The Tennessee Valley Authority developed a least cost network model to determine the cheapest refuelling schedule for nuclear reactors [Glover, Klingman and Phillips, 1989]. An airline uses an application similar to Feo and Bard's [1989] model for aircraft maintenance planning. And a chemical company uses network modelling to integrate production, inventory and distribution operations [Klingman, Mote and Phillips, 1988]. Network based models have also been used in mission critical applications such as air traffic control [Zenios, 1991].

The need to develop network models able to handle large scale problems is driving more recent work, such as that in the area of production planning by Bowers and Jarvis [1992], and processing environments [Chinneck, 1990].

The power of decision modelling has also been recognised by the medical community. Mathematical approaches to decision modelling in medicine have been exploited for over 25 years [Weinstein, 1996]. A number of these applications are discussed in Section 2.2.

2.1.5 Network Models with State Transitions

The Patient Flow Model represents a specialized application of the network modelling approach. In the traditional network model (examples include the transshipment problem, the shortest route problem and the maximal flow problem), there is only a single node type, and nodes fulfill a role that deals largely with managing routing choices through the network. In traditional network models, passing through a node causes no physical (or otherwise) change in the state of the entity being modelled.

An extension to traditional network modelling was proposed by Carl Adam Petri [1962] and has become known as the Petri Net. Petri's extension to network modelling introduced the concept of transitions — the idea that entities of interest (he called them tokens) moved from place to place[2] as a result of causal event (a transition). Petri's work became better known to the English-speaking world with the release of the Information System Theory Project [Holt, et. al, 1968] which translated Petri's PhD dissertation from German and extended the work.

One of the extensions to Petri's work proposed that the *transition* envisaged by Petri (which dealt with a causal event) could also be imagined to be an event that causes a change in the entity of interest as the entity moved from place to place [Peterson, 1981]. The concept of a

2 Petri's modelling approach uses the term "place" in lieu of the term "node".

transitional event that causes a change in the entity of interest is used extensively by the Patient Flow Model. In the Patient Flow Model, the transitional event[3] is viewed to cause a change in the *state*[4] of the entity (i.e., a patient) as the entity passes through the transitional event.

While Petri Nets and the Patient Flow Model share a common grounding (in they both are variants of a state/transition model), they are nonetheless quite different. These differences explain why Petri Nets are not used as a platform upon which to build the Patient Flow Model.

The first difference is that in Petri Nets, transitions play a secondary role to *places*. Transitions simply explain how tokens get from place to place. The user's primary focus is on the *place*. The opposite is true of the Patient Flow Model. While much of the decision making power of a Patient Flow Model comes from the ability to identify various patient *states* (which are analogous to Petri's *places*), the focus of a Patient Flow Model is on the Treatments received by patients (i.e., the transitions).

A second difference between the two modelling approaches is that the underlying logic of Petri Nets means that certain flow patterns are not allowed. (See Peterson [1981], p208) These "not allowed" flow patterns can be modelled using the netform approach taken by the Patient Flow Model.

And finally, while a technique for visually representing a Petri Net exists, the technique is not as visually rich as that developed to support the Patient Flow Model.[5]

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3 The focal transitional event in a Patient Flow Model is a Treatment. Chapter 4 (Section 4.3.2) introduces the concept of a non-Treatment activity. In the context of Petri Nets, non-Treatment activities are also transition events.

4 The term *state* in the context of the Patient Flow Model has a completely different meaning than the use of the same term in a Petri Net. (In a Petri Net model, state refers to the status of the network after the network has been fired. The Patient Flow Model uses the term *state* in the context of an identifiable characteristic of a patient.)

5 This is not to imply that the representation technique used for Petri Nets is not semantically rich.

2.1.6 Modelling Data Visually

By definition, netform modelling encompasses the use of a visual approach to modelling the data required to operationalise the network of interest. These diagramming techniques have emerged from those developed for data and network flow modelling [Glover, Klingman and Phillips, 1992, p1].

Data modelling has evolved over the past 30 years since the concept of a two level database architecture first emerged in the 1971 publication of the CODASYL database task group report [CODASYL, 1971]. The CODASYL report advocated an increased level of data independence by creating a distinction between database schemas (which provided a logical description of data) and user subschemas (which provided a view of the data as seen by the user.)[6] The two level architecture was key to supporting the emergence of Codd's [1970] relational database model.

Despite the advantages of the two level architecture, the architecture was found to have several problems. These included a difficulty in mapping between databases described using different data models, and many data description languages were unable to properly describe the logical properties of data because of their record orientation [Kent, 1978; Senko 1975]. This led to the emergence of a three layered architecture described in the ANSI/X3/SPARC proposal in 1975. The ANSI/X3/SPARC architecture expanded the schema concept to include external schemas (data as viewed by the user), internal schemas (data as it is managed, organised and stored by the system) and a conceptual schema (the link between the external and internal

[6] Prior to the proposal of a two level architecture, data structures were typically direct extensions of the record definition used in large scale file systems. No distinction was made between the logical and physical definitions of the data.

schema) [ANSI/X3/SPARC, 1975]. While there has been considerable discussion about the exact purpose/definition of the conceptual schema (see for example, Deen [1980]) a number of developments in data modelling helped strengthen the data architecture advocated by ANSI/X3 SPARC [1975]. Notable among these was the creation of the Entity-Relationship Model by Chen [1976].

The Entity-Relationship Model is significant to this research as it represented an early demonstration of the value in providing users of information systems (in this case relational database systems) with visual tools that can be used to portray the structures and underlying relationships inherent in data captured by an information system. Just as the Entity-Relationship model allows users to write down data manipulation commands by directly reading from an Entity-Relationship diagram, netform modelling allows users to "write down a mathematical version of a netform model directly 'from the picture' " [Glover, Klingman and Phillips, 1992, p1]. This direct mapping between the visual representation of the problem domain and the mathematical specification of the model is a powerful feature of the Patient Flow Model.

The acceptance of high level data models such as that used in the Patient Flow Model was spurred by the development of a number of such models in the 1980s. These developments included semantic models, object-oriented models and predicate logic models and are well chronicled by van Griethuysen [1982]. While it is expected that any of these approaches to data modelling could be used to gather and represent the data necessary to populate a Patient Flow Model, none of these approaches offers the opportunity to develop a visual representation of the problem domain that is directly mappable to the mathematical programming techniques used to operationalise the Patient Flow Model. It is for this reason that netform approach was selected as the technique used to provide a framework for the functional specifications of the Patient Flow Model.

So many types of high level data models were developed during the 1970s and 1980s that taxonomies emerged to help classify them. (See for example, Klein and Hirschheim [1987].) The proliferation of visual approaches to data modelling helped secure acceptance for visual data representation techniques as an accepted part of the information system development process. The strong acceptance of visual approaches to data modelling adds further support to the choice of a netform base upon which to build the functional specifications for the Patient Flow Model.

2.1.7 Advantages of Netform Modelling

Netform modelling combines the mathematical power of network modelling constructs with a visual representation of the problem domain. Netform modelling offers a number of advantages as a platform upon which to build a decision-support tool. Glover, Klingman and Phillips [1992, p8] organise these advantages around four dimensions.

1. Visual representation of the problem domain allows for improved communication between managers and model developers. This facilitates review and feedback.

2. Visual representation allows for improved model fidelity. The chances of omitting important relationships is decreased, as are the chances of inadvertently creating relationships that do not exist in the real world.

3. There is an opportunity for improved sensitivity analysis. Visual representation encourages the posing of *what if* questions.

4. It is easier to interpret results when the method by which the result is determined is portrayed visually.

2.1.8 Suitability of the Netform Approach for the Patient Flow Model

Using a netform approach as the platform upon which to build the Patient Flow Model allows the Patient Flow Model to capitalise on the four reasons responsible for the widespread use of netform models[7]. These are that:

a) the netform approach has a strong visual content;

The model's visual content will assist clinical providers and hospital finance specialists in both validating the design of Patient Flow Models and in the interpretation of results generated by Patient Flow Models.

b) the netform approach is extremely flexible;

It is possible to model a wide variety of patient/treatment interactions, and it is possible with the netform approach to easily modify the network to reflect changes in clinical practice or resource consumption profiles.

c) the netform approach is amenable to solution using mathematical techniques; and,

Linear programming techniques can be used to find optimal solutions to scenarios posed of Patient Flow Models.

[7] Reasons a) through c) are after Glover, Klingman and Phillips [1992]. Reason d) is after Jensen and Barnes [1980] and Bertsekas, [1991].

d) the problem definition and solution methods have also been well proven.

Network modelling provides a solid theoretical foundation to the Patient Flow Model.

2.2 Literature on Modelling Patient Flows

The previous section demonstrated the suitability of netform modelling techniques for addressing problems in the healthcare domain. This section develops this discussion by reviewing previous work in the area of modelling patient flows in healthcare settings. This section shows how the Patient Flow Model is a logical extension to the work completed to date.

2.2.1 Types of Models

The value of using modelling techniques drawn from the operations field has not been lost on the healthcare profession. There has been considerable interest in modelling techniques and a number of practical, small-scale applications have been developed. (See for example, Weiss, Cohen and Hershey [1982]; Davies [1994]; Roberts and Dangerfield [1990].) Applications to date have largely been problem specific. (For example, modelling patient flows to better plan for the use of operating rooms.) Models with a hospital-wide focus or application are scarce. Efforts typically involve modelling a small component of a much larger healthcare setting.

Modelling efforts to date can be broadly classified as having followed one of two approaches. The first approach involves developing models that focus attention on the arrival and uptake of patients by the facility. The second stream of research focuses on models of resource usage by patients. Each of these research streams is discussed in the following sections.

Models of Patient Arrival & Uptake

Models of patient arrival & uptake attempt to determine the appropriate combination of macro-level resources (such as beds, operating rooms, etc.) needed to accommodate patients who are admitted to the hospital in the order in which they arrive at the facility. Because the rate at which patients arrive at a hospital is random, these models are usually stochastic. Hindle's [1972] modelling of eye surgery patients was an early example of this approach.

More advanced software tools allowed subsequent authors to extend Hindle's ideas leading to Duma's [1984] hospital bed planning model, and Davies [1994] coronary care unit model. Newer tools also allowed advances in the presentation of model output. Jones and Hirsts [1987] work demonstrated the value of presenting model output in a visual format to enhance acceptance and use of the modelling technique by physicians.

Advantages & Disadvantages

The Patient Flow Model subscribes to this premise and incorporates an interface that is strongly visual. To some extent, Jones and Hirsts [1987] confirm in a medical setting what

Glover, Lingman and Phillips [1992] argue is one of the powerful advantages of using netform modelling approaches to solve problems with a focus of patient arrival and uptake.

Stochastic analytic models have also been developed. Hershey, Weiss and Cohen [1981], Kao [1974] and Weiss, Cohen and Hershey [1982] all explore Markov based approaches to modelling patient flows. Unfortunately, Markovian based approaches have a number of limitations (even when some pure Markov requirements are relaxed). These include difficulty in determining the route followed by a patient arriving in a particular state, and the inability to properly recognise the implications created by scarce resources. The mathematical techniques required to address these limitations are quite complex, and incorporating the increased mathematics makes the models too cumbersome for many users [Hershey, Weiss and Cohen, 1981].

In contrast to this, the use of discrete event simulation has proven to be much more amenable to developing credible models in healthcare settings because the conceptual underpinnings of the model are usually much easier to understand. Davies [1994] and Jones and Hirst [1987] use simulation models. Davies' [1994] model is a precursor to the design approach used by the Patient Flow Model. His model examined the treatment of coronary artery disease and allowed three possible paths through the treatment process. These paths were identical with respect to referral, admission and discharge. The paths differed with respect to whether a patient received surgery, bed rest or an investigative procedure. Davies' model is a precursor to the Patient Flow Model in that it was impossible under Davies' model for a patient to participate in more than one of the discriminating activities. The Patient Flow Model does not require paths through the model be pre-specified.

Models of Resource Usage

In contrast to models that focus on the uptake of patients by healthcare facilities, a second stream of literature focuses on models of resource usage by patients. These models have application in settings involving longer episodes of care. This is because while models built around patient arrival and uptake work well when the episode of care is measured in terms of hours or days, the ability to model resource usage becomes difficult if the episode of care is stretched to weeks and months (as might be found in long term care or psychiatric settings.) This is caused by the long term commitment of resources required when the episode of care expands. (In models involving short episodes of care, the ongoing discharge of patients constantly triggers the release of resources that can then be used by the patient uptake stream. In contrast, as the episode of care lengthens, each new admission creates a long term commitment of resources that are often not freed again for the duration of the model period.)

Advantages & Disadvantages

Resource based models often talk of patients as existing in particular treatment states. (The Patient Flow Model borrows this concept.) Treatments received are a function of the patient's state, the treatment plan in place, and the availability of resources. (Again, the Patient

Flow Model subscribes to these concepts.) Fisher and Dnesper [1983] and Perry, Lavori and Howe [1987] are representative of resource based models where the episode of care is long relative to the duration of individual treatments provided. A limitation inherent in these models is that patients move from state to state at fixed time intervals, giving the model a Markovian feel similar to some of the models developed for patient arrival and uptake. Because activities must be assumed to occur at the end of specific time periods (which usually are equal in duration) it is necessary to develop time slices that are relatively short when compared with how long a patient's treatment will last, or how long a patient will remain in a particular state. See for example, Wood, Malik and Wing's [1987] resource based approach to modelling renal failure or Roberts and Dangerfield's [1990] synchronous simulation in an HIV application.

A second limitation of deterministic models is the need to use homogeneous groups of patients. As the groups become larger, the incidence of co-morbidity increases.[8] This seriously complicates the mathematics required to solve models of this type. (See for example, Perry, Lavori, and Hoke [1987].) Vissers [1994] focusses solely on a statistical approach to measuring resource consumption and allocation.

As with the arrival and uptake models, simulation based models have proven to be powerful tools for resource based modelling. These models help identify constraints which limit the ability to provide care at the desired level. With some adaptation, these models can be tweaked to address queuing by patients for services. Some of these models are able to handle

[8] E.g., Homogenous group *A* might include patients with renal failure. Homogeneous group *B* includes cardiac difficulties. Co-morbidity is when a patient in Group A has the added complication of exhibiting symptoms belonging in Group B.

stretchable resources or the fetching of patients from alternate treatment paths. Davies [1984, 1987, 1994] has developed experience in this area.

2.3 Literature on Activity-Based Costing

In addition to exploiting the power of netform modelling, the Patient Flow Model has the added advantage of being able to track the utilisation and cost of resources required to provide hospital care. A number of costing methodologies have been developed for use in management accounting practice. The Patient Flow Model uses a methodology called activity-based costing. This section outlines the foundation of activity-based costing and demonstrates why activity-based costing is a suitable costing methodology to incorporate in the Patient Flow Model.

2.3.1 The Development of Cost Accounting

The recording of accounts for financial record-keeping can be traced to the early 16th century when the Venetian monk Fra Pacioli developed the technique for recording obligations between trading partners known today as double entry bookkeeping.[9] The conventions proposed by Pacioli form the foundation of the branch of accounting practice now known as financial accounting [May et. al., 1975].

[9] Although Pacioli is generally given credit for the introduction of double-entry bookkeeping, financial records in simpler forms are know to have been kept by early civilizations.

The primary purpose of financial accounting is the preparation of statements that summarise the financial activities of the firm and its current financial state of health. Financial accounting is largely an outwardly focused endeavour in that it uses historical data to generate information of potential value to agents external to the firm such as bankers, investors and regulators [CICA, 1996 (Sections 100.5 through 1000.12)].

While double-entry bookkeeping provided a methodology that could be used effectively to capture the details of transactions between trading partners, early bookkeeping methods were not designed to provide support for the internal decision making needs of management. This is because prior to the Industrial Revolution most multi-staged production processes were characterised by an explicit exchange transaction occurring after each stage in production. This made it easy to assign value at any of the intermediate conversion stages during production. As such, there was little impetus to develop mechanisms to measure intermediate conversion costs [Garner, 1954].

Two developments in the 1800s would provide an incentive for developing explicit measures of conversion costs. The first was the introduction of job shops - operations in which a proprietor hired employees to perform work on a piece basis. This required developing mechanisms to record production in order that each worker could be paid at the end of the day [Litterer, 1961]. The fact that externally validated transactions no longer occurred at the conclusion of each production process also meant that methods needed to be developed to capture the increase in value that raw materials underwent as they wound their way toward becoming finished goods [Scott, 1931].

A second development during this period was a move by some firms to manage multi-staged production processes using a captive labour force that would be paid on an hourly basis rather than on a piece basis. These firms quickly realised that the greatest profit gains came not from competing externally on the open market to buy intermediate inputs (such as yarn in the textile example), but rather from determining how to internally increase productivity and decrease costs [Johnson & Kaplan, 1987]. The need to manage productivity and control costs gave rise to accounting processes that could be used for administrative control, and represented the birth of a new branch of accounting practice known today as management accounting[10] [Chandler, 1977; Scott, 1931].

During this period, labour and materials represented the most value added components in the manufacturing process. Management accounting systems were therefore designed with a specific focus on these costs. Other costs, however, were incurred during the production process. Representative examples include electricity, rent, insurance, taxes, selling costs, and administrative overhead. Because these costs were difficult to trace directly to a specific product, management accountants needed to develop methods that could be used to *indirectly* associate these costs with products. Key to many of these methods is that they used some measure that was easily associated with a product (such as how many direct labour hours "Product *x*" required) to act as a surrogate for the measure that was difficult to determine (such as how much electricity was consumed during the production of Product *x*.) As Johnson and Kaplan [1987] point out, what relevance there once

10 The terms cost accounting and management accounting are often used interchangeably. This study considers cost accounting to be a process that focuses on *cost finding* - the processing and evaluation of cost data while management accounting involves the *use* of this information for purposes of planning and control.

was for using labour based allocation mechanisms is quickly disappearing in a manufacturing environment where labour no longer represents the most value added component.

2.3.2 The Need for Effective Cost Accounting Systems

While Johnson and Kaplan's 1987 book, *Relevance Lost* can be given credit for legitimising the need to develop more effective cost accounting systems, problems caused by using accounting systems based on single driver allocation mechanisms had already appeared in the literature.

Seed [1984] suggested that five changes were needed to improve cost accounting systems. While some of Seed's ideas (such as blending labour and overhead into a new cost category called *conversion costs*, and using market driven values to "rent" equipment to departments) would not be echoed as strongly by subsequent researchers, other concepts he advocated (such as treating all costs as direct, and developing better overhead allocation methods) have become cornerstones in the drive to revamp cost accounting systems.

Miller and Vollman [1985] talk of a *hidden factory* - a factory within the manufacturing facility that can be imagined to be incurring overhead costs. Miller and Vollman blamed the existence of the hidden factory on cost accounting systems that are unable to recognise what *causes* overhead. Howell and Soucy [1987] (like Johnson and Kaplan [1987]) recognised that cost accounting systems must provide information that supports multiple (and sometimes, conflicting) purposes. Howell and Soucy saw three user constituencies for cost accounting data. These were:

- inventory valuation;

- product costing; and
- process control.

Johnson and Kaplan [1987] provide a longer list of uses for effective costing systems. Among the uses envisaged by Johnson and Kaplan were:

- pricing decisions;
- decisions related to dropping existing products; and
- decisions related to new product introductions.

While Johnson and Kaplan's list was designed for the manufacturing environment, it applies equally well in the health-oriented service environment. The three uses proposed by Johnson and Kaplan are restated from a healthcare perspective as:

- funding decisions (based on the cost of providing patient treatments);
- decisions on whether to introduce a new treatment program (such as heart transplant); and
- decisions on whether to stop performing certain procedures at a particular facility (such as consolidating birthing units at one central hospital).

A common thread that runs through the pre-1987 literature is a call to move away from a single driver allocation base toward a method of associating costs with products in a way that more accurately reflects the *work* that products cause for the organisation. This "new" way of generating product costs would become known as *activity-based costing*.

2.3.3 Activity-based Costing

Activity-based costing is a methodology that attempts to determine what *causes* costs to be incurred, and uses this information to associate costs with cost objects in direct proportion to the work that the cost object causes for the organisation. Activity-based costing is based on the premise that cost objects (such as jobs, units, setups, etc.) cause organisations to engage in certain activities, and that activities in turn consume resources [Burch, 1994].

This approach differs from that used in traditional two stage allocation processes. Traditional (or volume based) costing systems first assign costs to cost pools and then distribute cost pools to products using a pre-determined burden rate as a cost driver. The burden rate may be based on direct labour hours, machine time, material dollars, or some combination of these factors. In all cases, however, overhead from the cost pools is associated with products in direct proportion to volume. It is this traditional approach that bears much of the criticism raised by Johnson and Kaplan [1987]. (See also Cooper and Kaplan [1988a].) These authors argue that costing errors result from the use of oversimplified apportionment rates [Shillinglaw, 1989].

Cooper [1992] comments on the intuitive appeal of the activity-driven approach to cost determination. In an earlier article, Cooper [1988a] demonstrates how activity-based costing can reduce cost distortions caused in environments producing a wide variety of products of differing volumes. He suggests that the firms able to benefit the most from activity-based costing are those with low data collection costs, operating in highly competitive markets, selling a diverse product mix.

These conditions exist in healthcare. Much of the data collection activity required to support activity driven costing is already in place. Hospitals employing the statistical chart of accounts proposed in the *MIS Guidelines* [CIHI, 1997a] have a wide variety of activity data available. While hospitals do not operate in the competitive environment envisaged by Cooper, they do function in an environment where pressures to deliver services in the most efficient and effective manner possible are an everyday reality. Lastly, the wide range of treatments provided by a hospital, with varying volumes for each, dovetails closely with Cooper's concept of a diverse product mix.

2.3.4 Activity-based Costing in Service Industries

While applications for activity-based costing have received much attention in a manufacturing setting, the same attention has not been paid to the application of activity-based costing in the service sector. Rotch [1990] provides one of the best overviews of applications for activity-based costing in service settings. He reviews applications developed by a hospital, a railway, and a data processing organisation. He notes how service industries have three characteristics that help distinguish them from their manufacturing colleagues:

- the output may be harder to define;
- activity in response to service requests may be less predictable; and
- joint capacity costs represent a high proportion of total cost and may be difficult to link to output-related activities [p8].

Cooper [1988a] also discusses potential challenges to users of activity-based costing in a service setting. He points out that the cost curve may rise quickly because of the need to gather increasingly accurate information, and that the benefit curve (i.e., the cost of errors) will not be known with any certainty.

2.3.5 Is Activity-based Costing Really Something New?

The attention that activity-based costing has received in the literature (and in practice) in the past few years begs the question of whether activity-based costing represents a new and improved way of determining product costs, or, if activity-based costing is little more than a new name for concepts already well entrenched in management accounting practice. Are in fact activity-based cost systems simply two stage allocation schemes that make use of an increased number of cost centres?

A number of authors have tackled this question. There appears to be consensus that while activity-based costing is built using constructs already familiar to management accountants (such as standard costs, cost centres, multi-staged allocation processes, etc.), its strategic implications and its extension into the domain of performance measurement warrant considering activity-based costing (and its second cousin, activity-based management) as techniques in their own right.

Troxel and Weber [1990] take this stance. They demonstrate how activity-based costing systems have gone through a three stage evolution process, beginning with systems that were designed for normal financial purposes, and culminating with systems able to provide strategic insights. It has been shown that activity driven systems do force companies to examine what they are doing from both a manufacturing and an accounting standpoint. Turney and Anderson [1989] provide an excellent illustration of this fact in their paper examining the introduction of a new accounting system for an electronic measuring equipment firm. The new system dispensed with many conventional management accounting reports including such stalwarts of management accounting practice as variance reporting, scrap and rework reports, and standard product costs. Shank and Govindarajan [1992] explore how activity-based systems can provide a foundation for strategic cost management. Their work extends Porter's [1985] value chain paradigm by showing how cost information (generated using activity driven principles) can provide information for strategic cost analysis, something Porter criticised cost accounting systems for not providing.

When Shillinglaw [1989] was asked to comment on the future of management accounting, he foresaw a role for activity-based costing as management comes to better understand cost behaviour, as information processing capabilities make the gathering and manipulation of the data cheaper, and as managers come to view the information generated by activity-based cost systems as being significant to their decision making process.

2.3.6 The Patient Flow Model and Activity-based Costing

The Patient Flow Model incorporates a number of features advocated by researchers in the activity-based costing field. A number of these features are listed below.

- The Patient Flow Model assumes that activities (i.e., treatments) cause costs to be incurred and not the product (i.e., patients) itself [Johnson, 1988].

- The purpose of activity-based costing is to provide better information for decision making, not necessarily to prompt instant changes to procedures [Cooper and Kaplan, 1988b]. The same is true of the Patient Flow Model.

- The Patient Flow Model is able to distinguish between facility sustaining costs, process (i.e., program) sustaining costs, batch costs and unit costs [Cooper, 1990; Cooper and Kaplan, 1991]

- The Patient Flow Model recognises the cost of unused capacity [Cooper and Kaplan, 1992].

2.4 Literature on Healthcare Costing

A motivating factor for the development of the Patient Flow Model is the need for better management planning, resource utilisation and resource costing tools for use in healthcare settings. This section provides an overview of existing Canadian practice in these areas and demonstrates how the Patient Flow Model is a logical extension of current endeavours. For comparison purposes, commentary is also provided on cost accounting systems used in American hospitals.

2.4.1 Canadian Practice

The origins of a standardised reporting system for Canadian hospitals can be traced to the publication of the Canadian Hospital Accounting Manual (CHAM) in 1968 by The Canadian Hospital Association. CHAM provided a standardised chart of accounts aimed at ensuring comparability among the financial results reported by Canadian acute healthcare facilities.

By 1980, the complexities present in the financial structures used by large healthcare operations could not be addressed by the relatively simple accounting constructs outlined by CHAM. The Canadian Hospital Association proposed that a project be undertaken to provide contemporary information systems guidelines that more accurately reflected current healthcare practice, and the change in information systems environments between the 1960s and the 1980s. After seven years of development, and testing at selected hospital sites, the *Guidelines for Management Information Systems in Canadian Healthcare Facilities* were released. [MIS Group, 1990, Frameworks & Functions, p1].

The MIS Guidelines [CIHI, 1997a] provide Canadian hospitals with a blueprint for the design of information systems able to address both internal and external reporting requirements. The Guidelines contain specifications for those sub-systems concerned with financial and performance reporting in a comprehensive healthcare information systems. These sub-systems include:

- *A financial general ledger*

    The financial general ledger specifications provide a comprehensive, standardised chart of accounts built using a hierarchical block coding system.

- A statistical general ledger

    The statistical general ledger parallels the structure of the financial general ledger, but is used to capture performance data, such as the number of prescriptions filled, the number of emergency patients seen, stillbirths, admission and discharge counts, etc.

- A workload measurement system

  The workload measurement system is used to capture data on labour use. Specialised workload measurement systems have been developed (or are in the process of being developed) for each functional area.

- A cost allocation system for service department costs.

  A system to allocate intra-service department costs using a reciprocal costing approach.

- A departmental dimension reporting system

  The departmental dimension reporting system traces all costs (and performance data) to specific departmental classifications within the functional centre framework. At the departmental dimension the hospital is able to determine the cost of operating departments such as laboratory, diagnostic imaging (x-ray), etc.

- A global dimension reporting system

  Global dimension reporting systems allocate costs from functional areas to specific patients. Global dimension reporting allows hospitals to determine the cost of treating individual patients.

Capital asset, maintenance, and materiel management sub-systems round out the suite of applications specified in the MIS Guidelines.

While provinces are moving quickly toward developing comprehensive and comparable financial information systems for departmental level reporting, efforts to develop systems able to provide global dimension costs[11] are not as uniform across the country. Ontario and Alberta have trial systems in place to gather preliminary global cost information, while Quebec has developed a parallel initiative (SIRACDOF[12])

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[11] Canadian hospitals refer to patient specific cost determination (such as the cost to provide Patient *x* with a lung biopsy) as "global dimension reporting." Global dimension costs are also called *case costs* in some provinces, such as Ontario.

[12] Système d'information reliant l'activité clinique aux données opérationnelles et financières.

2.4.2 Cost Accounting Systems in American Healthcare

The funding mechanisms used to support Canadian hospitals have not required Canadian hospitals to develop the sophisticated cost tracking systems present in U.S. hospitals where cost tracking systems were initially installed to support payment reimbursement. American hospitals have considerable experience in the design and implementation of cost tracking systems. Researchers have noted, however, that the uses to which cost information is put has influenced the design and structure of U.S. patient cost accounting systems [Hwang and Kirby, 1994]. In systems designed to support claims to insurance companies there may be an incentive to create systems that report the highest cost possible [Young, Socholitzky and Locke, 1982; Young, 1984]. For example, in revenue producing centres (such as medical testing) conducting more tests will have a positive impact on the hospital's bottom line. In an attempt to minimise this behaviour, U.S. insurers moved to a method of reimbursing hospitals based on a patient classification system using Diagnostic Related Groups (DRGs). Insurers assigned a pre-determined reimbursement factor to each DRG irrespective of the resources the hospital consumed to provide the treatment. This created an incentive for hospitals to move away from simply tracing costs to managing costs. Only with a complete understanding of their cost structure could U.S. hospitals ensure that the costs they were incurring were less than the DRG reimbursement rate.

The need for U.S. hospitals to track and report costs allowed for the development of considerable expertise in the creation of large scale cost reporting systems. The sophisticated nature of these systems, however, did not necessarily speak to the degree to which the costs they report reflect reality. The popular press routinely reports on the apparent absurdity of costs reported on the invoices of patients receiving care from U.S. hospitals. A Toronto Star [March 24, 1993, pB3] reporter discussed how he was charged $280.00 for 14 bundles of ice cubes wrapped in paper towels used at his wife's delivery.

These stories abound because, although U.S. healthcare cost accounting systems are sophisticated in the degree to which they can trace costs to patients, they suffer from many of the limitations noted of systems found in manufacturing [Counte, 1988]. Two stage allocation systems, with huge burden rates (up to 1000%) designed to allocate large amounts of overhead to relatively small amounts of direct supplies have created systems in U.S. healthcare that also suffer from "relevance lost" [Suver and Cooper, 1988].

Hanks [1988] reports on efforts to use some of the techniques proposed to cure the ails of manufacturing cost accounting systems in healthcare settings. Siegrist and Blish [1988] and Hemeon [1989] talk of how hospitals are beginning to rethink the objects of their costing process. Some hospitals are moving away from considering that their product is a patient's *stay* in the hospital (an analogy to a service laden hotel stay has been made) to considering that the hospital is in the business of managing a series of product lines (such as myocardial infarction treatments.) These authors note how much of a hospital's costs are overhead, and draw parallels to similar situations in advanced manufacturing settings. Although the parallel is striking, these authors fail to reconcile the fact that much of a hospital's fixed overhead cost consists of a nursing labour component, whereas advanced manufacturing facilities are usually characterised by their lack of a large committed labour force [Gosse, 1989].

Efforts to develop accounting information systems that can be used for cost management (in contrast to cost reporting) in healthcare settings are in their infancy, but reports of successful efforts to redesign systems are appearing. Chalos [1994] discusses how Massachusetts General Hospital used an activity-driven approach to completely redesign their patient transportation system (and in the process, to save money.) Rotch [1990] discusses the uses of activity-based costing methods by Alexandria Hospital where it was used to focus on the costs incurred during patient treatments instead of on costs incurred during patient stays.

2.4.3 Determining Patient Specific Costs

Canadian hospitals use a traditional, volume based, two stage allocation process to determine global dimension costs. Expenses are first charged to departmental categories in one of seven functional areas. Representative examples of functional areas include Diagnostic and Therapeutic Services (with departments such as imaging and laboratory), Ambulatory Care Services (with departments such as clinics and home care), and Administrative and Support Services (with departments such as Finance and Personnel.) Detailed records are also kept (using a parallel statistical chart of accounts) of the labour outputs from each functional centre.

The total costs charged to a functional centre are divided by the number of minutes[13] of worked labour produced by the functional centre to determine the value of one *unit of service*. To determine patient specific (i.e., global dimension) costs, patients are charged for the number of

[13] Nursing is an exception. The denominator in nursing is based on hours, not minutes.

units of service that they receive from each functional centre at the rate determined for one unit of service. By summing the value of all the units of service received by a particular patient, the total cost of treating the patient can be determined [CIHI, 1997a].

While the global dimension costing methodology provides a detailed mechanism to trace costs to patients, its reliance on a volume dependent denominator means that many of the criticisms levelled at manufacturing systems by Cooper and Kaplan [1988a] can also be made of the case costing systems used in Canadian hospitals.

2.5 Motivation for the Patient Flow Model

The literature shows that the Patient Flow Model is a logical merging of developments in three fields. From the healthcare sector has come a call for the need to develop the tools needed to assist managers with the task of accessing and manipulating large pools of data to explore a variety of planning and control issues [Whitt, Whitt, and Culpepper, 1991; Maggart, 1985]. Fiscal constraints, and the need to understand the implications of changes in funding models makes this need even more pressing.

The operational sciences have contributed knowledge in the area of netform modelling which has been shown to be a suitable method for modelling problems of the type addressed by the Patient Flow Model [Jensen and Barnes, 1980; Bertsekas, 1991]. Successful efforts to develop models for tightly focused decision-making needs have already been accomplished in healthcare settings [Davies, 1994; Perry, Lavorii et al. [1987]. And lastly, the advantages of using an activity-driven approach to developing cost information has been shown to overcome some of the limitations inherent in more traditional costing approaches.

Thus, the Patient Flow Model is a logical extension of the literature to date. The Patient Flow Model capitalises on the existence of well accepted approaches to modelling operational problems. The Patient Flow Model is designed to assist decision-makers in a sector (healthcare) where there has been a clear call for the need to have access to better tools for data manipulation. Because the Patient Flow Model recognises the link between operational flows and resource availability and cost, the Patient Flow Model builds a bridge between the domains of operational and financial decision-making. And the use of an activity-driven costing paradigm by the Patient Flow Model ensures that the financial decision-making component of the model reflects contemporary thinking in the area of cost determination.

2.6 Conclusion

This chapter provided an overview of the literature relevant to the development of the Patient Flow Model. The process by which ideas from the literature are transformed into a functional data modelling tool is an extrapolation which begins in the following chapter where the functional specifications for the Patient Flow Model are developed.

Chapter 3
Defining the Patient Flow Model

3.0 Introduction

The previous chapter demonstrated how the development of the Patient Flow Model is a natural blending of three streams of research. This chapter begins the process of formally defining the Patient Flow Model. Chapter Three provides the technical specifications of the Patient Flow Model and explains issues related to the model's functionality.[1]

A simple vaccination procedure is developed early in the chapter. The vaccination procedure is used to introduce the component parts of the Patient Flow Model and to demonstrate the model's functionality. The balance of the chapter extends this discussion by developing the formal specifications of the Patient Flow Model. These specifications include:

- an explanation of the purpose of each type of node used in the Patient Flow Model;

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[1] A brief discussion of the financial functionality of the model is presented during the discussion of Resource and Package Nodes. A detailed explanation of the method by which resource cost and consumption information is generated is deferred until *Chapter 4 - Tracking Costs and Resource Utilization.*

- details of characteristics and behaviour unique to each node;
- tables describing all parameters, variables, constraints and relationships associated with the model;
- the symbolic notation used to represent variables and parameters associated with the model; and,
- an introduction of the visual technique used to represent each node in a Patient Flow Model network diagram.

The chapter concludes by providing a comprehensive illustration of a Patient Flow Model based problem. Chapter Three also includes a discussion of issues that must be resolved during the model design stage in order to ensure the utility of Patient Flow Models to model users.

3.1 Conceptual Foundation

The Patient Flow Model is based on two premises. The first is that the interaction between a patient and a health care facility (such as a hospital) can be explained using a paradigm that considers patients to exist in a variety of *states*, each of which is a determining factor with respect to what *treatment(s)* patients will receive, and that the treatment(s) received by patients dictates what *resources* the hospital will use in order to provide care. That is, the Patient Flow Model explains the relationships that exist between patients, their conditions (*States*) the care they receive (*Treatments*), and the materials, labour and equipment available in the hospital (*Resources*).

The second premise upon which the Patient Flow Model is based is that the process of caring for patients involves a series of treatments. The objective of the treatment process is to move a patient from a state of poor health toward a state of better health. Patients *flow* from treatment to treatment between the point of admission and the point of discharge.

Receiving a treatment usually results in a change in the patient's condition. The Patient Flow Model capitalises on the repeated pattern of *existing state* → *treatment* → *new state* in order to develop network models that reflect patterns of care. The Patient Flow Model extends the network model to also capture the *flow* of resources used by each treatment in the provision of care.

While the treatment paradigm offers a means by which patients and their flow through a health care facility can be modelled, the Patient Flow Model has the added advantage of being able to recognise that patients with different medical conditions must often be cared for simultaneously. This requires patients to "compete" (or more accurately, their physicians must compete) to obtain the resources necessary to receive the treatments required to move from a state of poor health toward a state of better health. Given that fiscal realities usually place limits on the availability of resources, hospitals must search for ways to achieve their sometimes competing objectives of providing quality care to all patients while respecting budgetary constraints. The Patient Flow Model is well suited to helping resolve such problems. The conceptual foundation of the Patient Flow Model allows the use of mathematical modelling tools[2] to identify optimal outcomes given any profile of initial patient states and resource availability.

[2] The mathematical modelling tool used in this research is linear programming. Chapter 6 discusses how non-linear tools could be used to extend the functionality of the model.

3.1.1 The Important Distinction between Model Designer and Model User

This research distinguishes between the roles played by *model designers* and *model users*. Model users are defined as those persons who employ a Patient Flow Model for clinical or financial decision-making purposes. Model designers are defined as those persons responsible for conducting the analysis required to build Patient Flow Models, conveying the analysis in the context of a computerized tool, and gathering the requisite data to populate the model.

The ultimate test of the utility of a Patient Flow Model is whether the model adequately addresses the decision-making needs of a model user. Thus, before models can be built, it is imperative that model designers spend time to gain an in-depth understanding of the decision-making needs of the model user. The requirements of the model user will guide many of the decisions the model designer must make during the construction of the Patient Flow Model.[3] For example, the uses to which a Patient Flow Model will be put will influence (among other things) the of degree of aggregation used to portray clinical events, the amount of financial detail explicitly captured by the model, and possibly most importantly, the objective function used to operationalise the model. Throughout this and the next two chapters, rules and guidelines are provided to model designers to assist in making these choices and decisions.

[3] Chapter Five presents a detailed design methodology that can be used by model designers to identify and gather the information needed to build Patient Flow Models.

3.2 The Vaccination Example

To facilitate a discussion of the various components of the Patient Flow Model, and to demonstrate the model's functionality, an illustrative model is developed in this section. The example models a situation in which patients present[4] at an emergency department with a penetrating wound. It is assumed that the wound has been closed and the next step in the treatment protocol is to determine whether a tetanus vaccination is required.[5]

The scenario follows:

> A PHYSICIAN prescribes a tetanus vaccination to patients who have not been vaccinated in the previous 24 months. Patients with a recent vaccination are discharged. Experience has shown this represents 33% of patients. For those patients requiring a vaccination, the intervention requires an INJECTION be prepared by a NURSE using TETANUS VACCINE. The vaccination can be administered by either a NURSE or a PHYSICIAN. Patients emerge from the treatment in one of two states. Ninety percent of patients have NO REACTION to the vaccine, while the remaining 10% have a MILD REACTION causing a rash. Irrespective of their state, patients are discharged from the emergency department after receiving the vaccination.

The five components used to develop Patient Flow Models are seen in the visual representation of the vaccination scenario portrayed in Figure 3.2A. The five components are *Patient States*, *Treatments*, *Resource Packages*, *Pathways*, and *Resources*.[6]

The focal element in the Patient Flow Model is the *Patient State*. Patient States reflect information on the variety of conditions (or "States") in which a patient can exist during a treatment program. In general, patients move from a state of poor health to one of better health as a result of

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4 In medical settings, patients are said to "present". The term is analogous to "arrive."

5 Although not explicitly modeled, a number of treatments have already occurred. The patient has been monitored (data collected on the cause of the wound), diagnosed (penetrating wound with no arterial bleeding), prescribed (wound to be closed using sutures), intervened (sutures inserted) and the patient is now awaiting a subsequent diagnosis to determine whether a tetanus vaccination is needed.

6 Chapter Four introduces an optional sixth component used to explicitly model non-Treatment activities.

receiving treatment. *Patient State Nodes* (represented as circles in Patient Flow Model network diagrams) capture information about the various states in which a patient can exist.

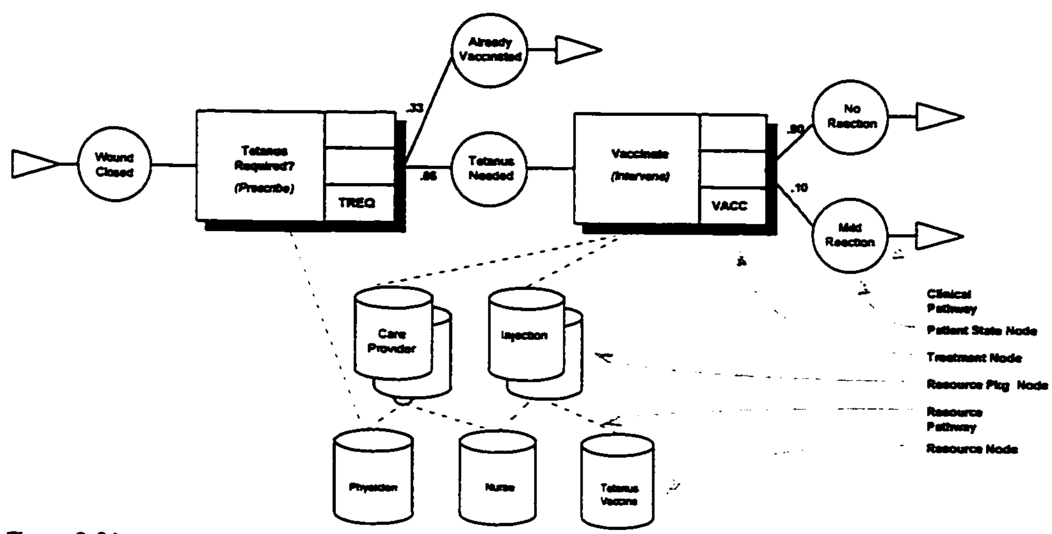

Figure 3.2A:
The Vaccination Example Illustrating the Component Parts of the Patient Flow Model

There are five patient states in the vaccination example. Patients either have their WOUND CLOSED, are ALREADY VACCINATED, have been classified as TETANUS NEEDED, have NO REACTION to the vaccination, or have a MILD REACTION. *All patients in a given state share the condition/symptom represented by the Patient State Node.* Thus, while some people who originally presented with a penetrating wound may be old and some may be young, or some may have cancer and some may not, with respect to the vaccination treatment, they are all in the same state because they have all had their WOUND CLOSED.[7]

[7] If it was necessary to distinguish between young and old patients, or between patients with and without cancer, this would be accommodated by creating separate patient state nodes.

Patients always enter and leave the treatment process via Patient State Nodes. In this simplified example, it is only possible to leave the treatment process in one of three states (ALREADY VACCINATED, NO REACTION, and MILD REACTION).

Rectangles (called *Treatment Nodes*) indicate chartable events.[8] The vaccination example illustrates two chartable events. One is a prescriptive treatment (TETANUS REQUIRED?) during which it is determined whether to vaccinate the patient. The other is an intervention treatment (VACCINATE). Most treatments cause a change in a patient's state. This change may be subtle (in that the only change may be that the patient has now had the treatment), the change may be pronounced (for example, there could be a significant increase or decrease in health), or the change may simply be that the patient's condition is now better understood (for example, diabetes may now have been confirmed).

Where it is possible for patients to emerge from a Treatment in more than one state, *Treatment Distribution Factors* indicate the proportion of patients emerging in each outcome state. In this example, only 66% of patients need a tetanus vaccination and of this 66%, 10% experience a reaction to the vaccine, while the remaining 90% have no reaction.

The resources (such as nurses, drugs, equipment, etc.) available for use in a hospital are reflected by *Resource Nodes*. Resources always have a cost (measured in dollars) and a unit of measure (such as hour or millilitre.) Resources are illustrated using a cylinder.

The need to consume Resources is driven by the series of activities that must occur in order to provide a Treatment. Activities create the need to gather a bundle of Resources together to form a *Resource Package*. Resource Packages of CARE PROVIDER and INJECTION are used in the

[8] Chartable events are occurrences recorded in a patient's official medical record (their "chart").

VACCINATE Treatment, and these Resource Packages are assembled using three different Resources – PHYSICIAN, NURSE, and TETANUS VACCINE. Resource Packages represent collections of Resources that are repeatedly consumed together in the same linear combination. *Package Nodes* indicate bundles of Resources gathered together to support a Treatment. Package Nodes are shown in Patient Flow Model network diagrams as two stacked cylinders. (The stacked cylinders remind the user that a Resource Package is simply a collection of Resources.)

The final component of the model are the *pathways* linking Patient State Nodes, Treatment Nodes, Package Nodes and Resource Nodes. Pathways represent arcs in the network model. Pathways linking Patient State Nodes with Treatments are *clinical pathways*. By default, clinical pathways flow along a horizontal axis and are generally drawn so that the default flow direction is from the left to right side of a Patient Flow Model network diagram. Flows along clinical pathways are measured in terms of patient numbers. Clinical pathways are shown using a solid line.

Pathways linking Resource Nodes and Package Nodes to other model components are called *resource pathways*. Resource pathways follow the vertical axis and by default move from the bottom of a network diagram toward the top.[9] Resource pathways are shown using a dashed line in Patient Flow Model network diagrams. Flows following resource pathways are measured in terms of *resource units*. When required, flows following resource pathways can be converted from resource units to dollars.

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[9] In the case of both clinical pathways and resource pathways, arrowheads are added to identify flows that are not moving in the default direction.

3.3 Formal Specification of Patient Flow Model Components

This section provides a detailed description of the five components of the Patient Flow Model. The purpose of each component is defined. The characteristics and behaviour of each component is explained, and where applicable, a discussion of model design considerations is provided. Figures illustrating both a general description and the formal symbolic notation are provided for each node. Each sub-section includes detailed tables containing descriptions of the parameters, variables, constraints and relationships associated with each model component. The mathematical relationships that allow the Patient Flow Model to be operationalised can also be found in these tables.

3.3.1 The Patient State Node ○

This section introduces the Patient State Node. The use and application of the Patient State Node is reviewed, together with characteristics and behaviour significant to the node. Constraints and relationships specific to this node are presented, and the symbolic notation used to formally specify attributes and properties of the Patient State Node is developed.

Purpose

Patient State Nodes reflect the condition (or 'state') of patients as they progress through a treatment program.

Characteristics & Behaviour

The Patient State Node is the key component of the Patient Flow Model. Characteristics of the Patient State Node permit the use of mathematical goal-seeking routines to "solve" problems posed of a Patient Flow Model, and in doing so, provide the Patient Flow Model with its normative modelling capabilities.

Patient State Nodes are analogous to decision nodes in traditional network models. Although the clinical pathways by which a patient can exit a Patient State Node are determined by the model designer, determining the number of patients actually flowing along each clinical pathway is calculated by the computerized tool used to implement the Patient Flow Model. Because Patient State Nodes are like decision nodes, there is no time value associated with a patient passing through a Patient State Node. Figure 3.3A illustrates clinical flows that enter and exit a Patient State Node.

Nothing about a patient's prior history can be inferred from his/her passing through a particular Patient State Node. (The nodes are said to be "memoryless.") For example, in the vaccination example, it is not possible to tell whether a patient who is in the TETANUS NEEDED state has previously had a vaccination. All that is known is that every patient in this state currently needs a vaccination.[10]

Flows entering a Patient State Node arrive by following a Clinical Pathway that originates from one of two sources:

1. *Admissions*

[10] If it was necessary to distinguish between patients who have and those who have not previously had a tetanus vaccination, two patient state nodes would be required.

Patients arriving from locations external to the area being modelled. Examples include new admissions, patients arriving from other hospitals, and transfers from other departments within the same hospital.

2. *Previous Treatments*
   Patients can also enter a Patient State Node via clinical pathways connected to Treatments that produce patients in the condition represented by the Patient State Node.

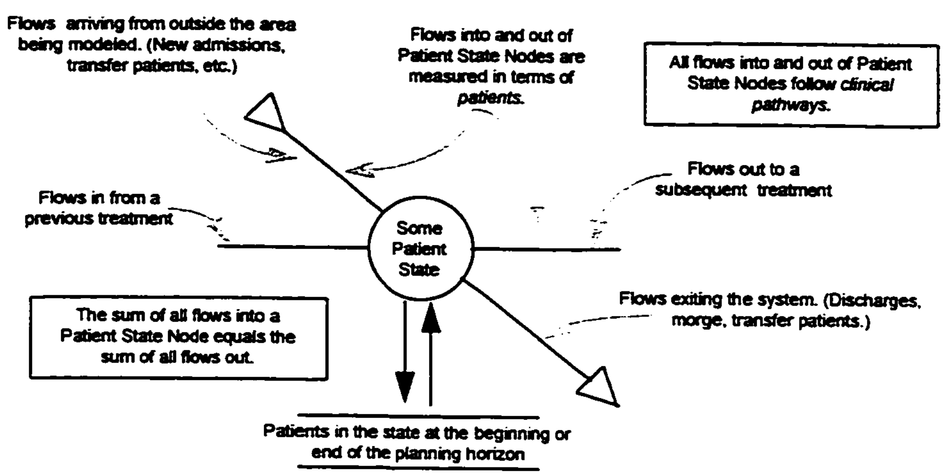


Figure 3.3A:
General Description of a Patient State Node

Patients leave Patient State Nodes by following Clinical Pathways that lead to either:

1. *Subsequent Treatments*
   Patients can exit a Patient State Node via clinical pathways connected to Treatments that accept patients in the condition represented by the Patient State Node.

2. *Separation*[11]
   Patients can exit a Patient State Node for locations are external to the area/program being modelled.

[11] Consistent with terminology used in hospital settings, exiting a Patient State Node for any reason other than progressing to a subsequent Treatment is called a *separation*. Separation can describe being discharged, being transferred to another program or hospital, or movements to the morgue.

The Patient State Node is also used to capture information on the number of patients in a particular state at the beginning and end of the planning period.

There is a balance of flows at each Patient State Node. The number of patients entering a Patient State Node during the planning period plus the number of patients already in the state represented by the node must equal the number of patients leaving the node plus the number of people remaining in the state represented by the node at the end of the planning period. Enforcing the balance of flows at each node allows mathematical solution techniques to be applied to the Patient Flow Model.

sum of inputs = sum of outputs

opening balance + new admissions + from prev. treatments = to subsequent treatments + separations + closing balance

Figure 3.3B
Patient State Node - Balance of Flows

The path by which a patient leaves a Patient State Node is usually determined by Resource availability and the objective being sought. There are a few situations, however, when the decision maker may wish to constrain the path followed by patients, even if doing so may not result in obtaining the optimal solution. For example, in a drug trial it might be decided to divide patients with angina into two groups. Fifty percent of patients are to receive treatment with drug A, while the remaining patients receive Drug B.[12] In the absence of a requirement to constrain the flow of

[12] If making the decision as to whether a patient should receive Drug A or Drug B requires the consumption of resources (e.g., a physician makes the decision, or the decision is based on the result of a lab test), the assignment of patients to the two drug regimes *must* be modeled using a Treatment node. This is because only Treatment nodes are able to access the Resources necessary to make the decision.

patients following an exit pathway, the Patient Flow Model will chose which drug to administer based on resource availability and the objective being sought.[13]

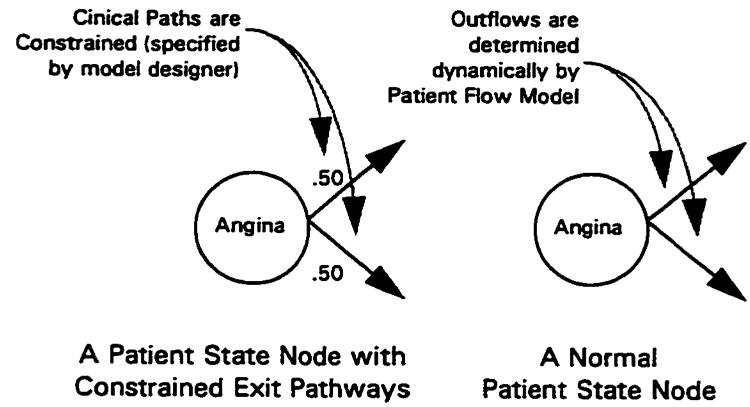


Figure 3.3C
Optionally Constraining Patient State Exit Pathways

Patients in a given state do not cause the hospital to consume resources and there is therefore no cost associated with a patient passing through a Patient State Node. (Patients may have "value", in that they have accumulated costs when they passed through previous Treatment nodes, but existing in a particular state has no cost in itself.) There is also no time value associated with a patient passing through a Patient State Node. Patients are assumed to exist in a particular state only momentarily as they move from one Treatment to the next. Patients are only "found" in Patient State Nodes at the beginning and end of the planning period. The *opening holding balance* parameter (E_i) and the *closing holding balance* variable (f_i) provide this information.

[13] Patients can also be forced to follow selected exit pathways from Patient State Nodes by specifying a minimum *occurrences* value for subsequent Treatments. There is an important distinction, however, between specifying a minimum occurrences value (which forces a specified number of patients to receive a specific Treatment) and constraining the output from a Patient State Node (which forces a specified *proportion* of patients to receive a specific Treatment).

Formal Specification

The following parameters and variables are associated with Patient State Nodes. A detailed description and comments regarding each parameter and variable can be found in Table 3.3A.

Parameters		Variables	
i	Identifier for a Patient State Node	r_i	Admissions
E_i	Opening Holding Balance	d_i	Separations
$RMIN_i$	Minimum Admissions Required	f_i	Closing Balance
$RMAX_i$	Maximum Admissions Allowed		
$DMIN_i$	Minimum Separations Required		
$DMAX_i$	Maximum Separations Allowed		
$FMIN_i$	Minimum Holding Balance		
$FMAX_i$	Maximum Holding Balance		
δ_{ij}	State Distribution Factor		

Figure 3.3D illustrates the formal specification of the Patient State Node.[14]

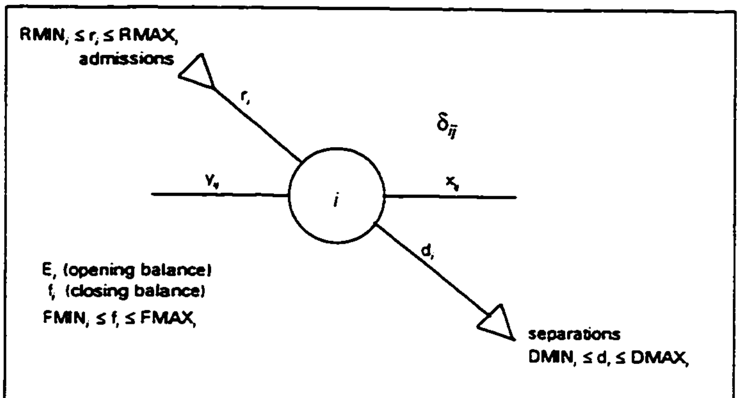


Figure 3.3D
Formal Specification of a Patient State Node

[14] Variables measuring the flow of patients following clinical pathways linking a Patient State Node to preceding and succeeding Treatment Nodes are treated as properties of the respective Treatment Nodes and are discussed in Section 3.3.2.

Table 3.3A

Patient State Nodes
Parameters & Variables

Notation	Parameter/Variable	Description	Comments
	Name	A short description of the condition of patients passing through the node.	
i	Identifier	A unique identification code.	Patient State Nodes have identifiers beginning with "S."
E_i	Opening Holding Balance	The number of patients in state i at the beginning of the planning horizon.	
$RMIN_i$	Min. Admissions Required	The number of new admissions that *must* be accepted* by the Patient State Node.	$RMIN_i$ is usually zero. Use values for $RMIN_i$ greater than zero in situations where it is necessary to force the model to accept patients.
$RMAX_i$	Max. Admissions Allowed	The maximum number of new admissions that can be accepted* by the Patient State Node.	$RMAX_i$ must be set to zero if admissions are not possible in state i, otherwise the model will "create" patients to admit in state i in order to achieve an optimal solution.
$DMIN_i$	Min. Separations Required	The minimum number of patients that *must* be discharged* in state i.	
$DMAX_i$	Max. Separations Allowed	The maximum number of patients that *can* be discharged* in condition i.	
δ_{ij}	State Distribution Factor	The relative proportion of patients leaving Patient State Node i for Treatment j.	$\Sigma(\delta_{ij}) = 1.0$ Values for δ_{ij} are only specified when there is a need to constrain the path followed by patients leaving a Patient State Node.
$FMIN_i$	Min. Holding Balance	The number of patients in state i that *must* remain in state i at the end of the planning horizon.	
$FMAX_i$	Max. Holding Balance	The maximum number of patients in state i that *can* remain in state i at the end of the planning horizon.	Setting $FMAX_i = 0$ forces all patients in state i to receive a subsequent Treatment.
r_i	Admissions	The number of patients arriving in state i from sources external to the area being modelled.	
d_i	Separations	The number of patients leaving the node in state i for destinations external to the area being modelled.	
f_i	Closing Balance	The number of patients who remain in state i at the end of the planning horizon.	$f_i = E_i + r_i + \Sigma(y_{ij}) - d_i - \Sigma(x_{ij})$

* during the planning horizon

Table 3.38

Patient State Nodes
Constraints and Relationships

Constraint/Relationship	Description	Comments
$RMIN_i \le r_i \le RMAX_i$	Actual admissions must be greater than or equal to the minimum required number of new admissions, and less than or equal to the maximum number of new admissions allowed.	
$FMIN_i \le f_i \le FMAX_i$	The number of patients remaining in state *i* at the end of the planning horizon must fall between the minimum and maximum limits set for the node's maximum holding balance	A value of 0 for $FMAX_i$ can be used to ensure that no patient remains in condition *i* at the end of the planning horizon. (For example, when modelling an outpatient program it is important to ensure that all patients are separated before the evening arrives.)
$r_i + \Sigma(y_{ij}) + E_i = d_i + \Sigma(x_{ij}) + f_i$	The number of newly admitted patients, plus the number of patients arriving in condition *i* from other treatments, plus the number of patients in condition *i* at the beginning of the planning horizon must equal the number of separations in condition *i*, plus the number of patients moving along clinical pathways in condition *i* to subsequent treatments, plus the number of patients in condition *i* at the end of the planning horizon.	This is a flow balancing constraint. Inputs = outputs.
$d_i, r_i, f_i \ge 0$	Admissions, separations, and closing balance must all be greater than or equal to zero.	

3.3.2 The Treatment Node 

This section presents the technical specifications of Treatment Node. The use and application of the Treatment Node is reviewed, together with details of characteristics and behaviour significant to the node. The symbolic notation used to formally specify attributes and properties of the Treatment Node is also introduced.

Purpose

Treatment Nodes capture details of the care-providing interactions between patients and the healthcare facility.

Characteristics & Behaviour

Treatment Nodes have four important characteristics that distinguish these nodes from all other nodes in the network. These are that;

a) Treatments take time to perform;
b) Treatments consume resources (and therefore incur costs);
c) Treatments involve direct patient care; and
d) Treatments usually cause a change in a patient's State.

Figure 3.3E illustrates the general description of a Treatment Node. Treatment Nodes are always connected to at least two Patient State Nodes. One Patient State Node must provide a flow of patients into a Treatment and at least one Patient State Node must accept the flow of patients leaving a Treatment Node.[15]

When there is more than one clinical pathway leading out of a Treatment Node, the proportion of patients following each possible clinical pathway is pre-specified by the model designer using statistical or subjective data. In the Vaccination example, it was seen that the Vaccinate treatment resulted in 10% of patients emerging in a state of MILD REACTION while 90% emerged in a state of NO REACTION.

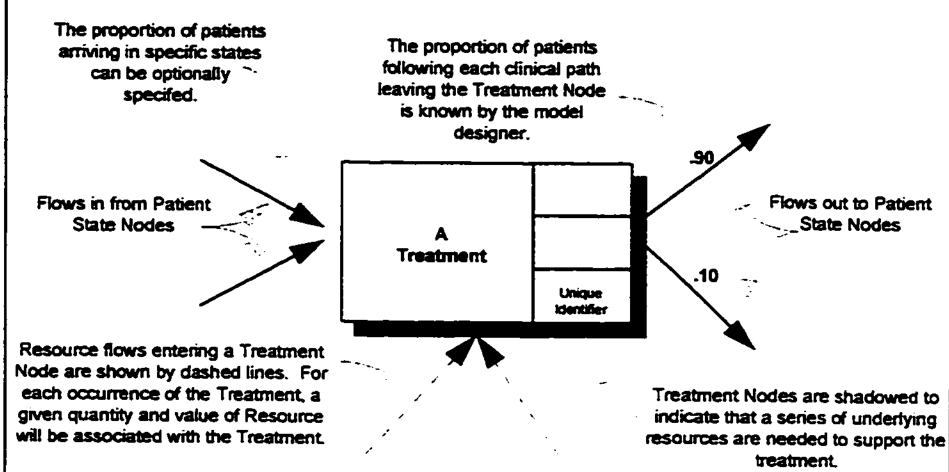


Figure 3.3E
General Description of a Treatment Node

When needed to suit the decision-making needs of the model user, it is possible to pre-specify a required mix of Patient States for patients entering a Treatment. For example, a substance abuse group session may require a combination of 50% chemical dependant patients and 50% alcohol dependant patients. The proportion of patients to be acquired from each of the Patient State Nodes immediately preceding a Treatment Node are denoted in the model using *treatment*

[15] In the special case of a monitoring Treatment, the Patient State Node providing the flow of patients into the Treatment can be the same Patient State Node that accepts the flow of patients exiting the Treatment.

acquisition factors. It was discovered during the research reported in this document that treatment acquisition factors are needed infrequently. In most cases, only the proportion of patients exiting a Treatment in each possible outcome state is specified as a part of the model design.

As with all other nodes, there is a balance of flows in the Treatment Node. The number of patients entering the node must equal the number of patients leaving the node.

sum of inputs = sum of outputs

patients arriving from previous Patient State Nodes = patients leaving for subequent Patient State Nodes

Figure 3.3F: Treatment Node - Balance of Flows

Clinical Protocols

While professional judgement on the part of medical practitioners is a valued and important component of providing medical care, the gaining popularity of evidence-based medicine and the desire to provide, monitor, and define "quality care," has resulted in the emergence of generally accepted treatment practices. Known by many names (e.g., CarePlans®, treatment plans, treatment protocols, and Care Maps®), generally accepted treatment practices specify the sequence of tests and procedures that should be undertaken to provide care for patients with a particular diagnosis. Best treatment practice standards ensure that all patients receive a consistent, high quality level of care which has been determined through clinical experience to result in the best possible prognosis.

The availability of best practices is exploited by using existing protocols (as determined by medical practitioners) to establish and specify routes that can be followed by patients in a Patient

Flow Model. Each route consists of a particular sequence of tests, assessments and procedures. The term *Clinical Protocol* is used by the Patient Flow Model to describe a best practices route through a series of Treatments.

Reported and Planned Treatment Time

Treatments take time to perform. The Patient Flow Model captures two dimensions of treatment duration. Values for both attributes are provided as part of the model design. The two dimensions of treatment duration are:

Reported Time	The time required (per patient) for the treatment. The default value for Reported Time is the value specified in the Workload Measurement System component of the MIS Guidelines [CIHI, 1997a].
Planned Time	The expected duration of the treatment (per patient) based on the health care facility's previous experience.

It is common for *Planned Time* to differ from *Reported Time* because the latter is based on national standards that may or may not reflect actual experience in a particular institution.[16] The Patient Flow Model is able to generate a pro-forma Reported Time and a pro-forma Planned Time report on a prospective basis for any sequence of treatments or patient load profile. This allows the Patient Flow Model to generate reports that complement a hospital's Workload Measurement Systems. An important feature of the Patient Flow Model is that workload measurement is integrated across all functional centres. This contrasts with the means by which Workload

16 The discussion in this section is based on workload reporting practices used in Canada. When used in settings other than Canada, the planned and reported time parameters can be assigned to similar attributes present in the modelling environment's geographic setting.

Measurement Systems are normally implemented. (Functional centres usually use dedicated (and often proprietary) Workload Measurement Systems.)

Reported time and planned time are measured in terms of *Reporting Time Units* (RTUs) and *Planning Time Units* (PTUs) respectively. Most users will set the value of one Reporting Time Unit or Planning Time Unit equal to one hour for nursing, and one minute for all other functional centres in order to remain consistent with the measurement methods used in the MIS Guidelines. Any number of minutes (hours/days/weeks, etc.) can be set equal to one RTU or PTU, as long as the measurement is consistent throughout the model.

In addition to a time parameter, all Treatments also have a cost associated with their occurrence. The cost is measured in *dollars*. The cost of a Treatment is calculated by determining the value of the Resources used to provide the Treatment.[17]

Abstraction

The level of abstraction selected for a Treatment Node can be varied to suit the model user's requirements. For example, it may be convenient to imagine the process of delivering a child as one treatment, DELIVER BABY. In other circumstances, it may be appropriate to model this intervention as a series of treatments such as PRE-NATAL MONITORING, DELIVERY and AFTERCARE. Any degree of abstraction can be handled by the Patient Flow Model which brings considerable flexibility to the modelling process.

[17] A complete discussion of the process of generating cost information using the Patient Flow Model appears in Chapter 4.

Abstraction decisions must be made during the model design stage, and as noted above, must be made after having due consideration for the types of decisions for which the model will be used by the model user. While it is often possible to recast a single Treatment as a series of subsidiary Treatments, or conversely, to recast a series of smaller Treatments as a more macro Treatment, the version of the Patient Flow Model reported in this research is not capable of dynamically recasting a clinical network from one level of abstraction to another.

Rules governing the abstraction process appear in *Section 5.1.2 - Specifying and Creating Patient Flow Models*.

Flow Patterns Through Treatment Nodes

The Patient Flow Model represents the process of providing medical care using four Treatment modalities. These Treatment modalities are:

Monitor	The process of *collecting data* regarding the patient's condition.
Diagnose	The process of *using data collected during monitoring to make an informed decision* regarding the patient's ailment.
Prescribe	The process of *specifying a medical intervention*[18] based on the patient's diagnosis.
Intervene	The process of *engaging in medical procedures* that have been prescribed.

[18] Medical procedures are referred to as "interventions." Examples of interventions are administering a drug or performing a surgical procedure.

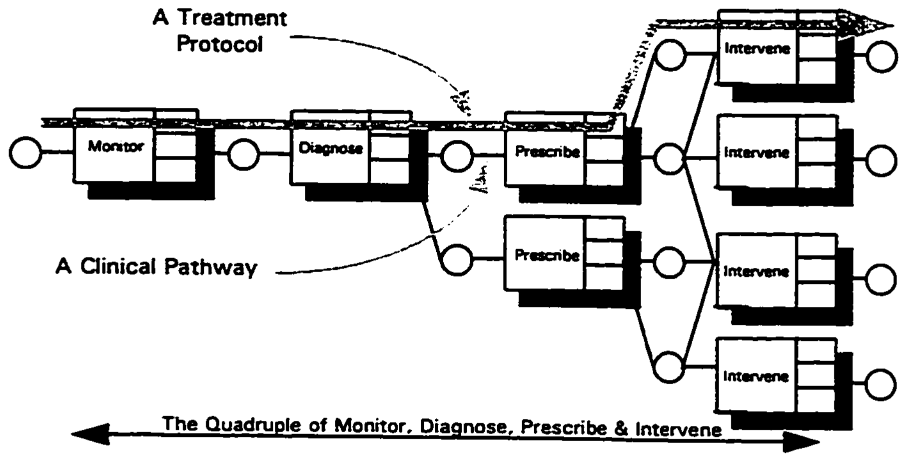
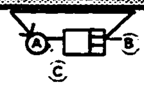
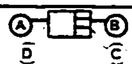


Figure 3.3G
The Four Treatment Modalities

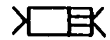
The quadruple of monitor, diagnose, prescribe and intervene is a treatment pattern prevalent in the Patient Flow Model. The pattern is shown in Figure 3.3G. The extent to which each step in the treatment process is explicitly modelled is a decision left to the model designer, and is made after considering the decision-making needs of the model user.

There are differences in the flow patterns associated with each of the four Treatment modalities. Some types of Treatments involve decision-making, while others do not. While any Treatment can have multiple exit pathways, only an Intervention has multiple input paths. A summary of the characteristics of each type of Treatment modality is presented in Table 3.3C. A visual illustration of the clinical pathway patterns associated with each Treatment modality is also presented.

Table 3.3C				
Characteristics of the Four Treatment Modalities				
Treatment Modality	**Clinical Pathway Pattern**	**Ratio of input to output paths**	**Decision Making?**	**Purpose**
Monitor		1:n (n ≥ 1)	no	Collect facts regarding a patient's condition. No change in the patient's state is required.
Diagnose		1:n (n ≥ 2)	yes (retrospective)	Use previously collected data to make a decision regarding patient's condition.
Prescribe		1:n (n ≥ 2)	yes (prospective)	Specify a future intervention based on the patient's diagnosis.
Intervene		n:m (n,m ≥ 1)	no	Engage in a medical procedure.

Both Diagnose and Prescribe Treatments involve decision making. Treatment Distribution Factors must be provided when specifying these Treatment modalities in a Patient Flow Model. A Diagnose Treatment reflects a retrospectively-based decision, in that the decision as to which clinical pathway a patient will follow is made by examining evidence *previously* collected from sources such as diagnostic tests, medical histories, or direct observation. A Prescribe Treatment reflects a prospectively-based decision, in that the decision as to which clinical pathway a patient will follow is based on the need to specify (i.e., "prescribe") a *subsequent* Treatment or series of Treatments.

Table 3.3D



Treatment Nodes
Parameters

Notation	Parameter/Variable	Description	Comments
	Name	A short description of the treatment.	
i	Identifier	A unique identification code.	Treatment Nodes use short mnemonic identifier codes. VACC is the identifier for the VACCINATE treatment in Figure [crossref].
$WMIN_i$	Min. Occurrences Required	The minimum number of times treatment i must be provided during the planning horizon.	In most cases, $WMIN_i = 0$, however, licensing requirements may specify that some procedures be performed a given number of times. $WMIN_i$ can be used to force the model to respect these eligibility requirements.
$WMAX_i$	Max. Occurrences Allowed	The number of times Treatment i can be performed during the planning horizon.	
β	Treatment Distribution Factor	The proportion of patients leaving a Treatment via each clinical pathway.	The proportion of patients leaving a Treatment in each possible exit states is determined by the model designer.
γ	Treatment Acquisition Factor	The proportion of patients arriving at a Treatment Node via each possible entry pathway.	Optional parameter.
X_eMIN and X_eMAX	Min. and Max. Constraints on Treatment Acquisitions	The minimum and maximum number of patients that can be accepted by Treatment i via clinical pathway x_e.	Optional parameter.
Y_eMIN and Y_eMAX	Min. and Max. Constraints on Treatment Distributions	The minimum and maximum number of patients that can be leave Treatment i via clinical pathway y_e	Optional parameter.
t_i	Duration	The time required to perform one occurrence of the treatment.	Can be stated in two terms: RTU The duration of the treatment according to standards set in The MIS Guidelines [1996]. PTU The duration of the treatment according to past experience at the facility.

Table 3.3E

Treatment Nodes
Variables

Notation	Variable	Description	Comments
x_{ij}	Inflow Count	The number of patients entering Treatment *j* in State *i*. There is one Inflow Count value for each Clinical Pathway entering the Treatment Node.	If Treatment Acquisition Factors are used, $x_{ij} = \gamma_{ij} \cdot w_j$ otherwise, values for x_{ij} are determined dynamically when the model is solved.
y_{ij}	Outflow Count	The number of patients emerging from Treatment *j* in State *i*.	There is one Outflow Count value for each Clinical Pathway leaving a Treatment Node. Is calculated as: $y_{ij} = \beta_{ij} \cdot w_j$
w_j	Occurrences	A count of the total number of times Treatment *j* was provided	$w_j = \Sigma(x_{ij})$ (*Occurrences* will always equal the sum of all Inflow Count flow values because all patients arriving at a Treatment Node receive treatment during the planning horizon.)

Table 3.3F

Treatment Nodes
Constraints and Relationships

Constraint/Relationship	Description	Comments
$WMAX_j \leq w_j \leq WMAX_j$	The number of Treatments provided must fall between the minimum number required and the maximum number allowed.	
$\Sigma(y_{ij}) = \Sigma(x_{ij})$	The number of patients entering a Treatment Node must equal the number of patients leaving the node.	

Formal Specification

The following parameters and variables are associated with Treatment Nodes. A detailed description, and comments regarding each parameter and variable, is presented in Tables 3.3D and 3.3E respectively.

	Parameters		Variables
j	Identifier for a Treatment Node	x_{ij}	Inflow Count
T_j	Duration	y_{ij}	Outflow Count
$WMIN_j$	Minimum Occurrences Required	w_j	Occurrences
$WMAX_j$	Maximum Occurrences Allowed	z_{kj}	Resource Inflow Count
$X_{ij}MIN$	Minimum Treatment Acquisition Constraint		
$X_{ij}MAX$	Maximum Treatment Acquisition Constraint		
$Y_{ij}MIN$	Minimum Treatment Distribution Constraint		
$Y_{ij}MAX$	Maximum Treatment Distribution Constraint		
β_{ij}	State Distribution Factor		
γ_{ij}	Treatment Acquisition Factor		
α_{kj}	Resource Equivalency Factor		

Relationships and constraints associated with Treatment Nodes are described in Table 3.3F. A visual representation of the symbolic notation associated with Treatment Nodes appears in Figure 3.3H.

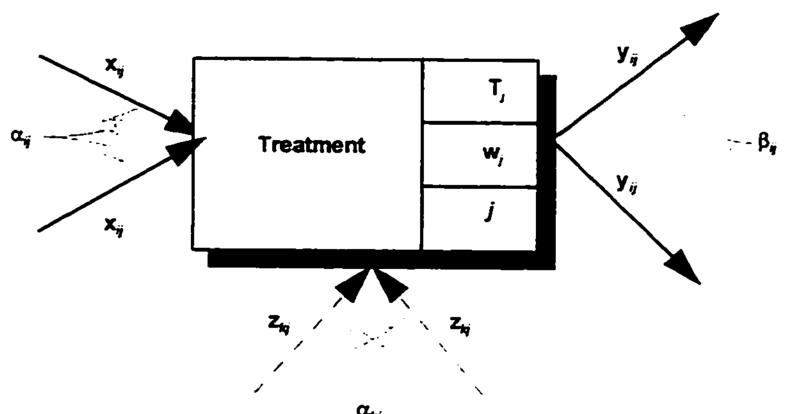


Figure 3.3H
Formal Specification of a Treatment Node

3.3.3 Resource Nodes

This section introduces the Resource Node. The role of the Resource Node in the Patient Flow Model is discussed, and characteristics and behaviour significant to the node are reviewed. The symbolic notation used to denote attributes and specify relationships and constraints related to the node is also introduced. Issues related to the accounting treatment of Resource Nodes is deferred to *Chapter 4 - The Resource Dimension: Tracking Costs & Resource Utilization*. This section focuses on the technical specification of the Resource Node.

Purpose

Resource Nodes represent the materials, labour, and equipment required to provide care to patients.

Characteristics & Behaviour

All financial data generated by the Patient Flow Model is based on cost data associated with Resource Nodes. Resource Nodes are shown in Patient Flow Model diagrams using a *cylinder* shape.

sum of inputs = sum of outputs

supply of Resource + Opening Balance = use of Resource + Closing Balance

Figure 3.31
Resource Node - Balance of Flows

As with all nodes in the network, there is a conservation of flow in Resource Nodes. Newly acquired resources, plus those on hand at the beginning of the period must equal the quantity of the Resource used plus the balance on hand at the end of the planning horizon. Flows into a Resource Node represent the *supply* of a Resource acquired after the planning horizon began. The *supply* flow captures details of Resource acquisitions made during the planning horizon. Flows leaving a Resource Node reflect use of the Resource.

There can be any number of flows leaving a Resource Node (in that many Treatments may have need for the Resource), but there is only one flow (called *supply*) leading into the node.[19]

The supply and use of a Resource is measured in terms of *Resource Units*. The Patient Flow Model allows users to select an appropriate unit of measurement for each Resource. For a drug, the Resource Unit chosen might be *millilitre* or *dose*. *Hours* might be an appropriate Resource Unit to select for Resources such as nurses and operating theatres.

[19] Depending on the resource, the supply arc either captures details of new purchases made during the planning horizon (such as buying additional units of a drug), or the arc captures details of previous purchases that need to be recognized during the current planning horizon (such as depreciation amounts on equipment.) This is the spending versus consumption distinction raised by Cooper and Kaplan [1992].

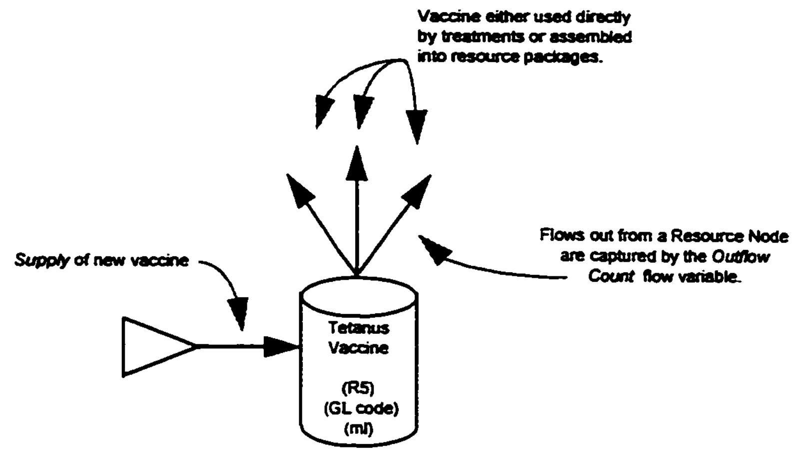


Figure 3.3J:
General Description of a Resource Node

Resources are often purchased in quantities larger than the Resource Unit. To accommodate this, users are able to specify both an *Acquisition Quantity* (some multiple of the Resource Unit) and an *Acquisition Cost*. The model uses these parameters to determine *Cost*. For example, tetanus vaccine may be purchased by the vial at a cost of $45.00 (the acquisition cost.) Each vial contains enough vaccine for 10 doses (the acquisition quantity.) The Patient Flow Model calculates the *Cost* of tetanus vaccine Resource as $4.50 per dose.

A mechanism to distinguish between Resources that are physically depleted when used (such as a drug), and those where the Resource remains relatively unchanged after use (such as a stethoscope) is developed in Chapter Four. (See Section 4.5.1 - Persistent and Consumable Resources.)

Formal Specification

The parameters and variables associated with Resource Nodes are presented below and are more fully described in Table 3.3G and 3.3H respectively.

Parameters		Variables	
k	Identifier for a Resource Node	s_k	Supply
E_k	Opening Balance	$z_{k\bullet}$	Outflow Count
Q_k	Acquisition Quantity	w_k	Occurrences
A_k	Acquisition Cost	f_k	Closing Balance
$FMIN_k$	Minimum Closing Balance Required	c_k	Resource Cost
$FMAX_k$	Maximum Closing Balance Allowed		
$SMIN_k$	Minimum Supply Required		
$SMAX_k$	Maximum Supply Allowed		

Details of the constraints and relationships found in Resource Nodes appears in Table 3.3I. A visual representation of the symbolic notation used by Resource Nodes appears in Figure 3.3K.

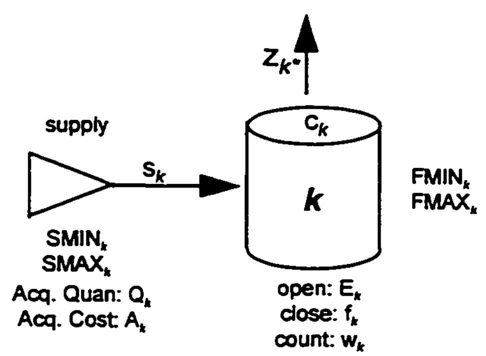


Figure 3.3K
Formal Specification of a Resource Node

Table 3.3G

Resource Nodes
Parameters

Notation	Variable	Description	Comments
	Name	A short description of the resource.	
k	Identifier	A unique node identification code.	Resource Nodes have identifiers beginning with "R" concatenated with the *secondary account code* for the resource's expense category as it appears in The MIS Guidelines [CIHI, 1997a].
	Resource Unit	The unit of measurement used when describing quantities of the Resource.	
E_k	Opening Balance	The number of Resource Units of k available at the beginning of the planning horizon.	
Q_k	Acquisition Quantity	The number of Resource Units acquired in one unit of s_k (*supply*).	
A_k	Acquisition Cost	The cost of purchasing Q_k.	
	Type	A flag used to indicate whether k is a Persistent or Consumable Resource.	Relates to the accounting treatment given to residual quantities of k.* See Chapter 4 for details.
$FMIN_k$	Min. Closing Balance	The number of Resource Units of k that *must* remain on-hand at the end of the planning horizon.	Set $FMIN_k > 0$ to create minimum inventory levels*, e.g. a quantity of blood to have available at the beginning of the following period.
$FMAX_k$	Max. Closing Balance	The maximum number of Resource Units of Resource k than can remain on-hand at the end of the planning horizon.	Set $FMAX_k > 0$ to force consumption of k, *even if* this would not otherwise occur given the objective function. (e.g. Force consumption of an expensive drug that will expire if not used, even if cheaper substitute drugs are available.)
$SMIN_k$	Min. Supply Rqd.	The number of times that Q_k *must* be acquired during the planning horizon.	Set $SMIN_k > 0$ force the acquisition of k, even if the k is not needed to sustain Treatments. For example, $SMIN_k$ can be used to force the model to purchase (and pay for) a full shift of nurses when only part of the shift is needed.
$SMAX_k$	Max. Supply Avbl.	The maximum number of times that Q_k can be acquired during the planning horizon.	For most consumable Resources, $SMAX_k$ is infinite. $SMAX_k$ also serves as a means to ensure the model does not acquire Resources in order to find a feasible (but unrealistic) solution. For example, if an X-ray machine was able to provide 10,000 images during the planning horizon and the demand for X-rays is for 10,005 images, the model will seek to acquire another X-ray machine to handle the 5 extra x-rays. Setting $SMAX_k = 0$ prevents the model from purchasing another X-ray machine.)

Table 3.3H

Resource Nodes Variables

Notation	Variable	Description	Comments
s_k	Supply	The number of times that Q_k is purchased during the planning horizon.	
$z_{k\bullet}$	Outflow Count	The number of Resource Units of *k* used by a parent node.*	$z_{k\bullet} = (w_\bullet)(\alpha_{k\bullet})$
w_k	Occurrences	The total number of Resource Units of *k* used.	$w_k = S(z_{kh})$
f_k	Closing Balance	The amount of *k* remaining on-hand at the end of the planning horizon.	$f_k = E_k + (s_k * Q_k) - w_k$
c_k	Resource Cost	The cost of one Resource Unit of *k*.	$c_k = A_k / Q_k$
	Resource Value Used	The dollar value of the Resource used.	Resource Value Used = $c_k * w_k$ *Resource Value Used* can also be determined for a specific flow arc by multiplying *Outflow Count* for that arc by the *Resource Cost Unit*. This gives the dollar value contribution that the Resource Node has made to the parent Package Node. $(c_k * z_{kh})$
	Cost of Unused Capacity	The value of *k* that was not used and must be included as a period cost during the planning horizon.	Applies only to Persistent Resources. Cost of unused capacity = $f_k * c_k$

Table 3.31

Resource Nodes
Constraints & Relationships

Constraint/Relationship	Description	Comments
$SMIN_k \leq s_k \leq SMAX_k$	*Supply* must be greater than or equal to the minimum supply required, and less than or equal to the maximum supply available of Resource *k*.	
$FMIN_k \leq f_k \leq FMAX_k$	*Closing Balance* must fall between the minimum and maximum limits specified.	
$(s_k * A_k) + E_k = S(z_{kh}) + f_k$	New Resource Units bought plus the opening balance of units on-hand must equal the sum of Resource Units used plus the number remaining on-hand at the end of the planning horizon.	(A flow balancing constraint.)
$s_k, f_k, w_k, z_{k\cdot} \geq 0$	*Supply, closing balance, occurrences* and all *outflow counts* must be greater than or equal to 0.	

3.3.4 Package Nodes 

This section outlines the purpose of the Package Node and describes the node's characteristics and behaviour. The symbolic representation used to denote parameters and variables associated with the node is then introduced.

Purpose

Package Nodes provide a mechanism to build a link between Resources and Treatments in situations where either,

a) the link is not clearly evident, or

b) decision-making can be enhanced by providing information regarding the intermediate activities that lie between the acquisition of the Resource and its use in a Treatment.

In both cases, Package Nodes indicate a set of Resources that are always used jointly.

Characteristics & Behaviour

Package Nodes represent a bundle of Resources that are always needed at the same time and in the same linear combination.[20] The bundle of Resources is measured in terms of a *package unit*. For example, potatoes, meat, a cook, and kitchen equipment taken individually are elemental Resources, but in combination create a meal. The "meal" is an example of a Resource Package.

[20] The ability to handle Resources that are used in a non-linear manner is discussed as a potential extension to the Patient Flow Model in Chapter Six.

Explicitly modelling the MEAL package in a Patient Flow Model makes it possible to generate information on the cost and utilization of meals by patients. (In the absence of the meal package, the only information available is the quantity and cost of potatoes eaten, etc.)

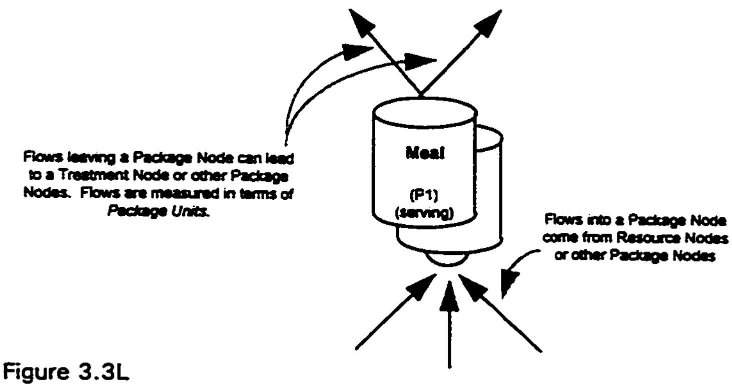


Figure 3.3L
General Description of a Package Node

The Resource Package represented by a Package Node is only assembled when there is a demand (i.e., a need) for the Resource Package.[21] The need to assemble the Resource Package represented by a Package Node is driven by events occurring elsewhere in the Patient Flow Model (such as the need to perform a Treatment).

Package Nodes normally have Resource Nodes as their children and Treatment Nodes as their parents, however, when necessary to better reflect the problem domain, Package Nodes can have other Package Nodes as parents.

[21] A subsequent extension to the Patient Flow Model will allow Resource Packages to be assembled in advance of there being a need for the Resource Package. (Inventory properties must be added to the Package Node functional specification to accommodate this enhancement.) See Section 6.3.4.

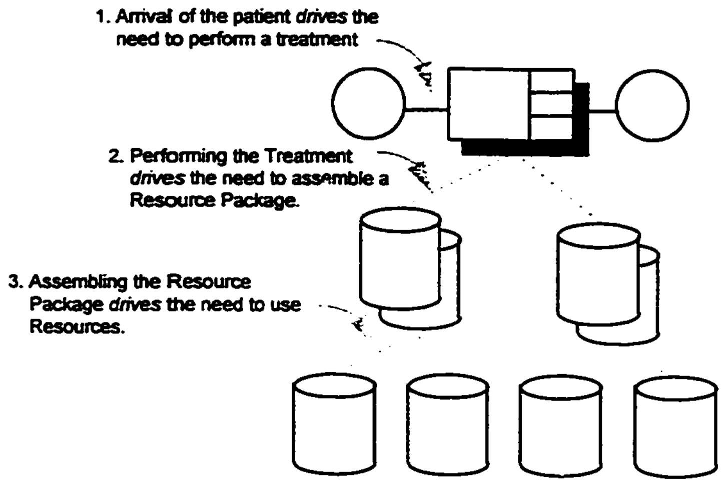


Figure 3.3M
Assembling Resource Packages

Selective versus Inclusive Assembly of Resource Packages

When assembling Resource Packages, there are occasions when two or more Resources (or other Resource Packages) are able to act as acceptable substitutes for one another. For example, if the objective is to find a solution that minimises cost, and a resource package can be assembled using any linear combination of resources A, B, or C, the Package Node will select and use the cheapest Resource until its supply is exhausted. Only then will subsequent packages be assembled using the more expensive Resources. Selective assembly (situations when the Package Node is able to choose from a range of Resources) implies "OR" and is shown by Resource Pathways that terminate at a small half circle on the bottom of a Package Node. The inclusive assembly of Resources (when the Package Node must use flows from all incoming arcs) implies "AND" and is shown by Resource Pathways that simply terminate on the bottom of a Package Node. Examples denoting inclusive and exclusive use of Resources appear in Figure 3.3N.

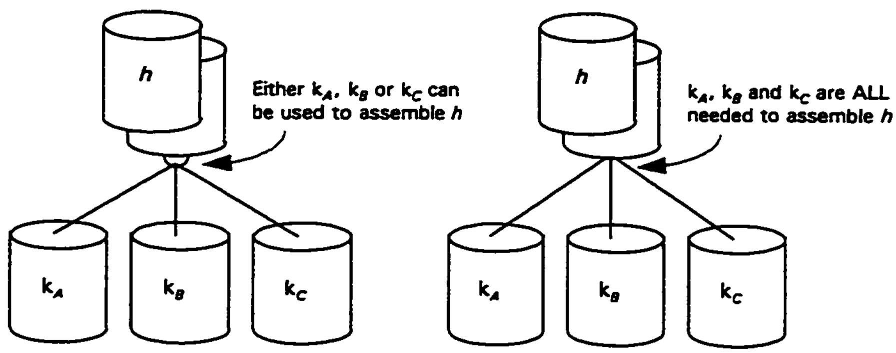


Figure 3.3N
Denoting Inclusive/Selective Assembly of Parent Nodes

Equivalency Multipliers

Equivalency multipliers (denoted as $\propto$) explain the cardinality of the relationship between parent and child notes in the Treatment - Package Node - Resource Node hierarchy. The equivalency factor indicates how many Resource Units or Package Units of a child node are needed for each occurrence or assembly of the parent node. Figure 3.3P adds *equivalency multipliers* to the Resource Packages and Treatments in the tetanus vaccination example.

For example, the *equivalency multipliers* in Figure 3.3P indicate that 2.0 billing units of a PHYSICIAN time *or* 0.05 hours of the NURSE Resource are needed to assemble a single CARE PROVIDER package. (e.g., If 100 vaccinations are performed, either 200 billing units of physician time *or* 5 hours of nurse time, *or any linear combination thereof*, will be needed.) The INJECTION package requires .1 hour of NURSE *and* 15ml of TETANUS VACCINE. An *equivalency multiplier* of 1.0 is implied whenever a factor value is not indicated for a Resource Pathway.

While equivalency multipliers (i.e., values for α) and treatment distribution factors (i.e., values for β) both appear as real numbers in a Patient Flow Model network, there is an important distinction between these two parameters. Equivalency multipliers are absolute numbers that explain the cardinality of a relationship. In contrast, treatment distribution factors are relative proportions and always add to 1.0.

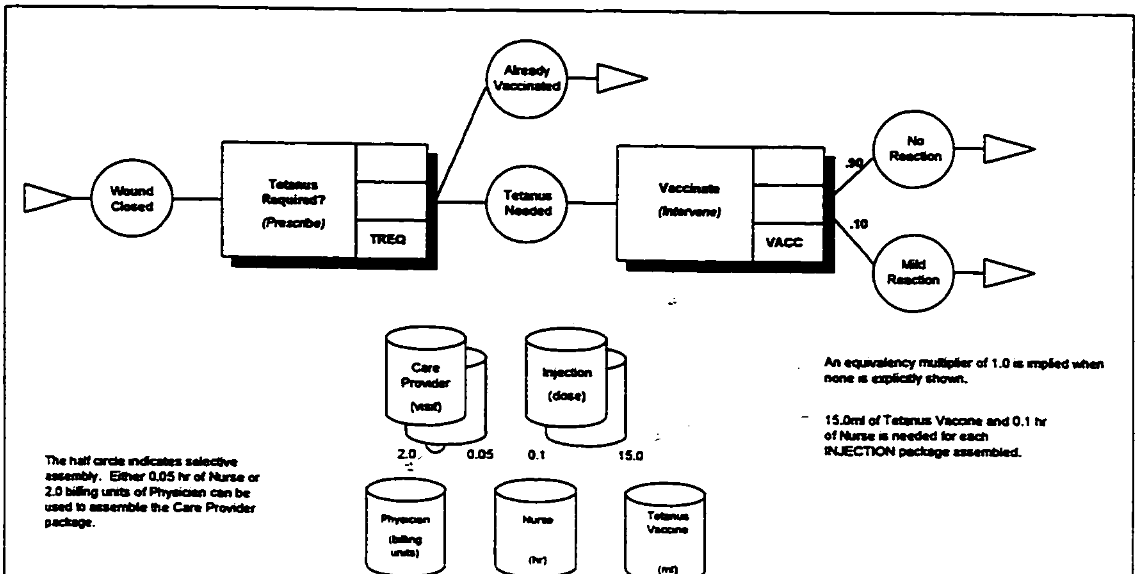


Figure 3.3P
Adding Equivalency Multipliers

Formal Specification

The parameters and variables used to define the Package Node are presented in Table 3.3J. Constraints and relationships which describe the behaviour and functionality of the node are presented in Table 3.3K. The symbolic representation used to formally specify a Package Node is visually presented in Figure 3.3Q.

Table 3.3J

Package Node
Parameters & Variables

Notation	Variable	Description	Comments
	Name	A brief description of the Resource Package, created when possible using a noun.	
h	Identifier	A code used to uniquely identify the node.	"P" + primary account code from MIS Guidelines.
$WMAX_h$	Max. Package Count	The maximum number of times that the package can be assembled.*	Normally $WMAX_h = ¥$. (w_h is usually constrained by limits placed on the quantity of Resources available.)
	Package Type	The cost classification of the event represented by the Resource Package.	Resource Packages are either encounter supporting, batch supporting, program sustaining or facility sustaining. The cost classification system is developed in Chapter 4.
	Package Unit	The unit of measurement used when describing one assembly and use of a Resource Package.	
$z_{h\cdot}$	Outflow Count	The number of *package units* used by a parent node.	$z_{h\cdot} = w_{\cdot} * \alpha_{h\cdot}$ There is an outflow count value for each Resource Pathway leaving the node.
w_h	Occurrences	The number of times Resource Package h was assembled and used during the planning horizon measured in *Package Units.*	$w_h = \Sigma(z_{N}) + \Sigma(z_{M\cdot})$
C_h	Package Cost	The cost to assemble one Resource Package.	$c_h = \Sigma(\mu_{\cdot h} * c_{\cdot})$
	Package Value Used	The total cost of assembling the number of resource packages represented by w_h.	Resource Package Value = $w_h * c_h$

* during the planning horizon

Table 3.3K

Package Nodes
Constraints & Relationships

Constraint/Relationship	Description	Comments
$w_h \leq WMAX_h$	The number of Resource Packages assembled must be less than the upper limit specified by the user.	
$(z_{\bullet h} / \alpha_{\bullet h}) = \Sigma(z_{h\bullet})$	Resource Flows entering a Package Node must equal Resource Flows leaving the node.	
$z_{h\bullet} = w_{\bullet} * \alpha_{h\bullet}$	The *outflow count* for each pathway leaving a Package Node equals the *treatment count* (or *package count*) of the parent node times the *equivalency multiplier* for the pathway.	
$w_h, z_{h\bullet} \geq 0$	*Occurrences* and all *outflow counts* must be positive.	

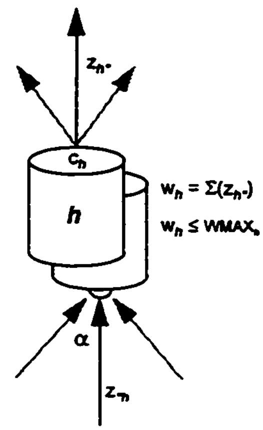


Figure 3.3Q
Formal Specification of a Package Node

3.4 Summary of the Formal Specification

This chapter introduced the five components of the Patient Flow Model. These components are Patient States, Treatments, Resources, Resource Packages and Pathways. A summary of node characteristics appears in Table 3.4A.

Table 3.4A

Selected Characteristics of the Four Types of Nodes Used in a Patient Flow Model Network

Model Element	Can Capture $?	Can Capture Time?	Ending Balance Allowed?	Inflow Mgmt	Inflows Accepted From	Outlow Mgmt.	Outlows Sent To
Treatment	No	Yes	No	Solved (User option)	States Packages Resources	User	States
State	No	No	Yes	Solved	Treatment Admission	Solved (User opt)	Treatment Separation
Resource	Yes	No	Yes	Solved	Purchases	User	Package Treatment
Resource Package	No	No	No	Solved	Resource	User	Treatment

Table 3.4A provides a handy reference guide for users who need quick access to information regarding the allowable linkages for each type of node. The purpose and key characteristics of each node is summarised in Table 3.4B. A summary of the symbolic notation used in the Patient Flow Model can be found in Appendix A. Figure 3.4A provides a visual summary of the symbolic notation and provides a comprehensive illustration of the Patient Flow Model network.

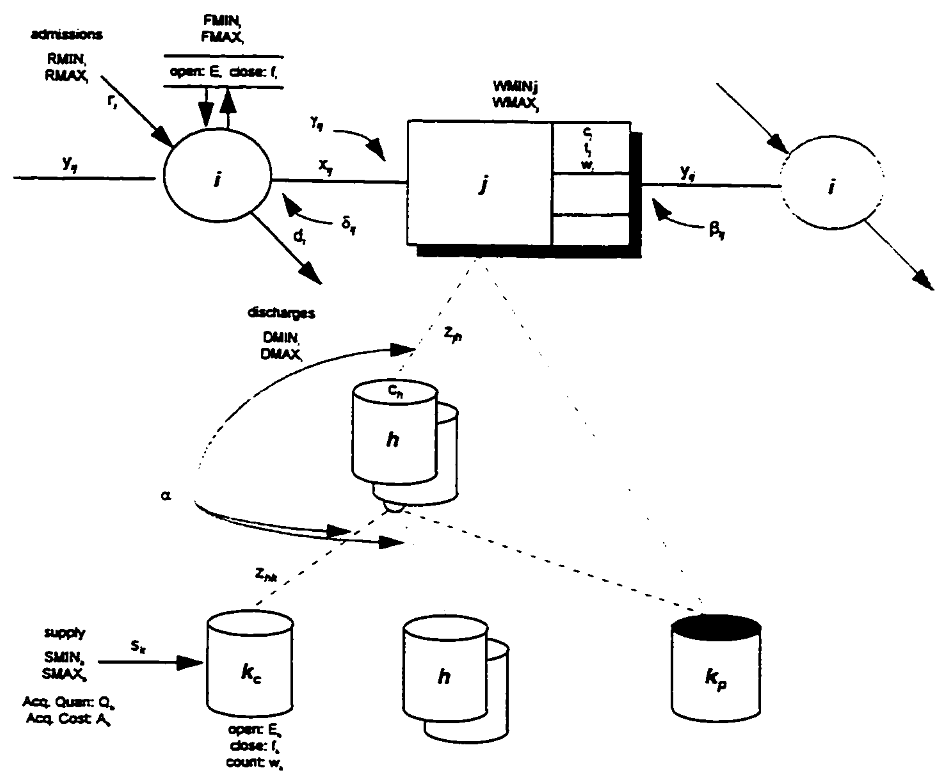


Figure 3.4A:
Comprehensive Illustration of Formal Model Specification

Table 3.4B

Summary of Model Components Used in the Patient Flow Model

Component	Purpose	Key Characteristics/Behaviour
Patient State Node	Reflect the condition (or "State") of patients as they progress through a treatment protocol.	Memoryless (nothing about a patient's prior history can be inferred by his/her passing through a Patient State Node.) Patients in the same State are indistinguishable from one another. Contain data on number of patients in a particular State at the beginning and end of the planning horizon. Patients entering + patients already in state *i* = patients exiting + patients remaining in state *i*. Act as decision nodes unless exiting clinical pathways are constrained.
Treatment Node	Capture details of interactions between patients and the healthcare facility.	Treatments take time to perform. Treatments consume resources (and therefore have a cost.) Sum of inputs = sum of outputs. Treatments usually result in a change of patient's State. Four types: Monitor; Diagnose; Prescribe; Intervene.
Resource Node	Represent the materials, labour and equipment required to provide care to patients.	All financial information generated by Patient Flow Model originates from data found in Resource Nodes. Sum of inputs = sum of outputs.
Package Node	Provide a mechanism to build a link between Resources and Treatments in situations where the link is not clearly evident or decision-making is enhanced by providing information on the intermediate non-Treatment activities that lie between the acquisition of a Resource and its use in a Treatment.	Sum of inflows = sum of outflows. Can have either Package Nodes or Treatments as parents. Can have either Resources or Package Nodes as children. Can take time to assemble. Have a cost.
Pathway	An arc along which either patients or Resources flow.	

3.4.1 Selecting a Structure to Represent Patient Flow Model Data

The Patient Flow Model supports complete independence between the formal specifications used to define the model[22] and the method used to represent the data structures required for a computerized implementation. This is an important feature of the Patient Flow Model. This feature ensures the model designer can select a data structure that best meets the operational requirements of the model user while also satisfying performance requirements of the model designer with respect to the chosen implementation strategy.

A number of strategies for data representation are available to the model designer. For many Patient Flow Model designers, it is expected that a frequently chosen data representation structure will be database oriented. Hierarchical, network or relational implementations are possible [Tsichritzis and Lochovsky, 1982]. The choice of a specific database structure will be driven to a large extent by the database management system (DBMS) chosen to store the data used by the Patient Flow Model. The current popularity of tools such as Oracle in the mid to large-scale computing environment, and Microsoft Access in the small to mid-range computing environment, suggests that many model designers will favour relational based data representations.

In order to illustrate how the data used by the Patient Flow Model can be represented in a relational database environment, the data required by the Patient Flow Model is normalised in Table 3.4C as a set of nine relations that are in Boyce-Codd normal form.

---

[22] These formal specifications are outlined in this chapter.

Table 3.4C

Normalised Representation of Data Used in the Patient Flow Model

Relation	Type	Attributes	Data Type	Data Source
Resource	Entity	ResourceIdentifier	alphanumeric	model designer
		Description	alpha	model designer
		UnitOfMeasure	alpha	model designer
		OpenBal	real	model user
		MinSupply	real	model user
		MaxSupply	real	model user
		AcqQuantity	real	model user
		AcqCost	real	model user
		Supply	real	solved by model
		CloseBal	real	solved by model
		UnitCost	real	calculated by model
Assemble	Relationship	ResourceIdenfier (composite key)	alphanumeric	model designer
		PkgIdentifier (composite key)	alphanumeric	model designer
		EquivFactor	real	model user
		Flow	real	solved by model
ResourcePkg	Entity	PkgIdentifier (key)	alphanumeric	model designer
		Description	alpha	model designer
		UnitOfMeasure	alphanumeric	model designer
		Occurrences	real	solved by model
ReqdBy	Relationship	PkgIdentifier (composite key)	alphanumeric	model designer
		TrtmtIdentifier (composite key)	alphanumeric	model designer
		ReportedTimeUnits	real	model user
		PlannedTimeUnits	real	model user
		MinOccurrences	real	model user
		MaxOccurrences	real	model user
		Occurrences	real	solved by model
Change	Relationship	TrtmtIdentifier (composite key)	alphanumeric	model designer
		StateIdentifier (composite key)	alphanumeric	model designer
		TrtmtDistributionFactor	real	model user
		Flow	real	solved by model
FlowInto	Relationship	StateIdentifier (composite key)	alphanumeric	model designer
		TrtmtIdentifier	alphanumeric	model designer
		TrtmtAcquisitionFactor	real	model user
State	Entity	StateIdentifier (key)	alphanumeric	model designer
		Description	alpha	model designer
		OpenHoldBalance	real	model user
		MinCloseHoldBalance	real	model user
		MaxCloseHoldBalance	real	model user
		MinAdmissions	real	model user
		MaxAdmissions	real	model user
		MinSeparations	real	model user
		MaxSeparations	real	model user
		Admissions	real	solved by model
		Separations	real	solved by model
		CloseHoldBalance	real	solved by model
Consume	Relationship	TrtmtIdentifier (composite key)	alphanumeric	model designer
		PkgIdentifier	alphanumeric	model designer
		EquivFactor	real	model user
		Flow	real	solved by model

The normalised relations in Table 3.4C can be recast in a visual form using Chen's [1976] Entity-Relationship diagram technique. The resulting Entity-Relationship model appears in Figure 3.4B.

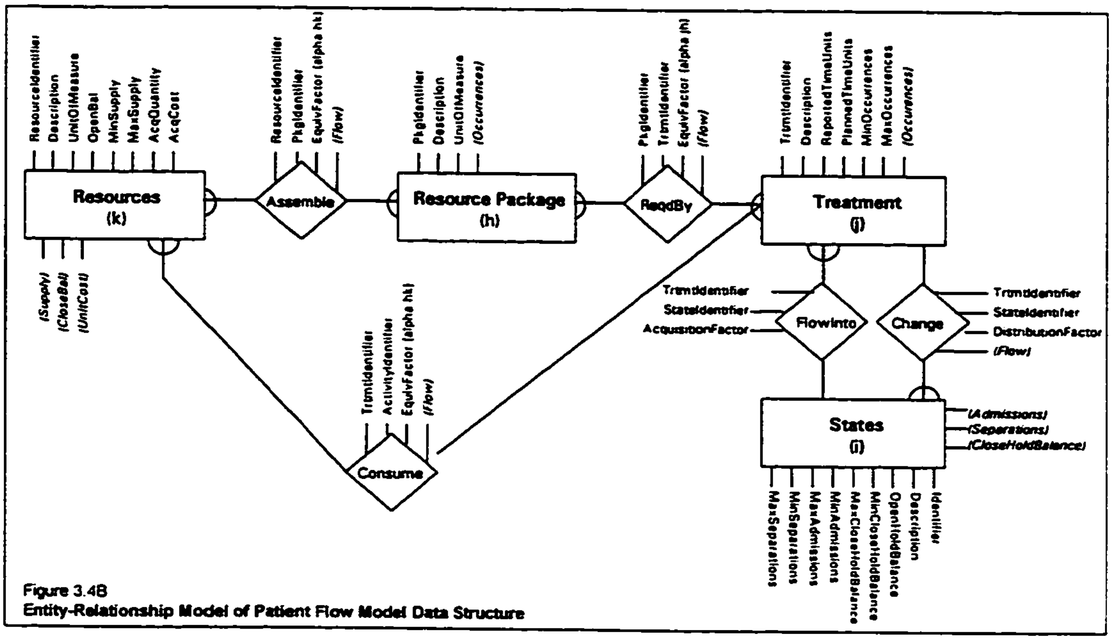


Figure 3.4B
Entity-Relationship Model of Patient Flow Model Data Structure

Other data representation structures are also possible. For example, object-based representations could also be employed. (See Rumbaugh et al. [1992] or Graham [1991] for a discussion of object-oriented approaches to data analysis and representation.) And at the opposite end of the spectrum, far from the robustness of relational or object-oriented representations, Patient Flow Model data can also be stored using an x-y co-ordinate matrix as found in common spreadsheet applications.

This latter approach was used in the demonstration models developed as part of this research. As will be discussed in Chapters Five and Six, spreadsheets provided an excellent prototyping environment in which to explore the Patient Flow Model's functionality. Spreadsheets were found, however, to have two serious limitations. One was that the built-in linear programming routines lacked the ability to handle the number of constraints and variables that are found in anything other than a relatively simple model environment. The second is that the use of an x-y co-ordinate structure to store data elements needed by the Patient Flow Model results in a relatively sparse matrix. This requires additional storage requirements, and also poses a problem for the type of linear programming engines incorporated with spreadsheets. Thus, as Chapter Six argues, commercial implementations of the Patient Flow Model should make use of an approach to data storage approach that is independent of the data presentation and data manipulation tools chosen.

3.5 Formal Specification of a Complete Model

A detailed description of the formal specifications for each component in the Patient Flow Model has been provided in this chapter. This section integrates the formal specifications of individual network components to illustrate a comprehensive applied example of a Patient Flow Model.

The Vaccination example introduced in Section 3.2 is used again in this section. Figure 3.5A reproduces the Vaccination network diagram from Section 3.2 for ease of reference. Node identifiers used in the formal specification of the model have been added to the network diagram to assist the reader in linking the diagram's contents with the mathematical specification for the model which follows.

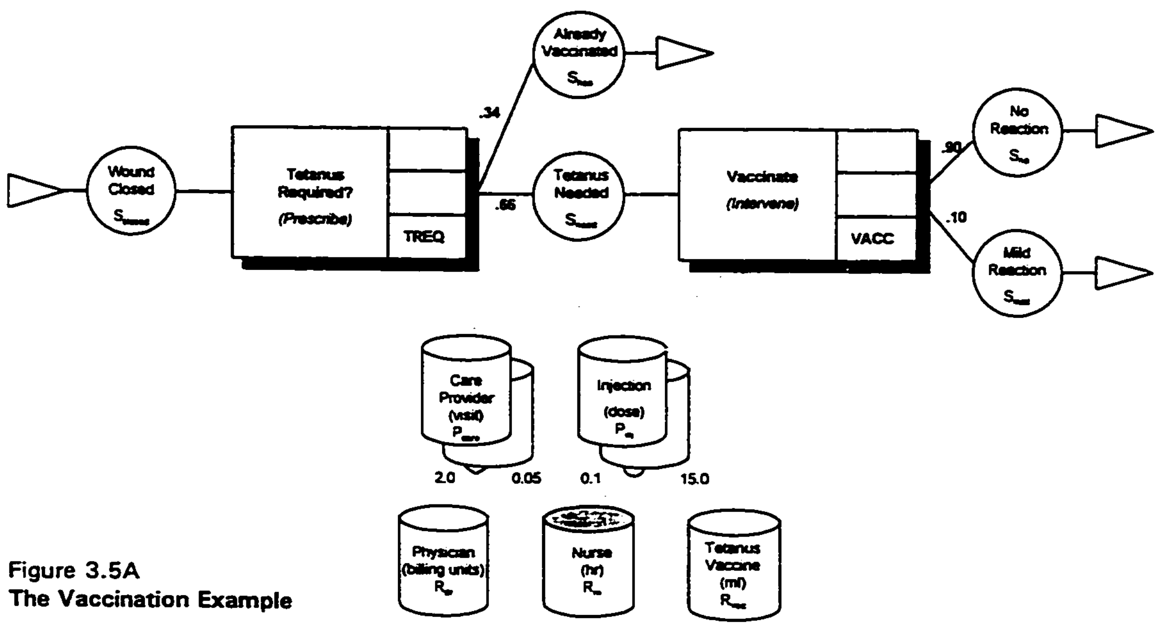


Figure 3.5A
The Vaccination Example

The following data is used to populate the Vaccination model:

for Resource Node R_{dr}.

$E_{R(dr)} = 0$	$Q_{R(dr)} = 1$	$A_{R(dr)} = \$18$
$FMIN_{R(dr)} = 0$	$FMAX_{R(dr)} = 0$	$SMIN_{R(dr)} = 0$
$SMAX_{R(dr)} = 200$		

for Resource Node R_{rn}.

$E_{R(rn)} = 0$	$Q_{R(rn)} = 40$	$A_{R(rn)} = \$20$
$FMIN_{R(rn)} = 0$	$FMAX_{R(rn)} = 40$	$SMIN_{R(rn)} = \$20$
$SMAX_{R(rn)} = 2$		

for Resource Node R_{vac}

$E_{R(vac)} = 1000$	$Q_{R(vac)} = 50$	$A_{R(vac)} = \$1000$
$FMIN_{R(vac)} = 1000$	$FMAX_{R(vac)} = 9999$	$SMIN_{R(vac)} = 0$
$SMAX_{(vac)} = 9999$		

for Patient State Node S_{closed}

$E_{S(closed)} = 10$ $RMIN_{S(closed)} = 0$ $RMAX_{S(closed)} = 0$
$DMIN_{S(closed)} = 0$ $DMAX_{S(closed)} = 0$ $FMIN_{(closed)} = 0$
$FMAX_{S(closed)} = 0$

for Patient State Node S_{has}
$E_{S(has)} = 0$ $RMIN_{S(has)} = 0$ $RMAX_{S(has)} = 0$
$DMIN_{S(has)} = 0$ $DMAX_{S(has)} = 9999$ $FMIN_{(has)} = 0$
$FMAX_{S(has)} = 0$

for Patient State Node S_{need}
$E_{S(need)} = 0$ $RMIN_{S(need)} = 0$ $RMAX_{S(need)} = 0$
$DMIN_{S(need)} = 0$ $DMAX_{S(need)} = 0$ $FMIN_{(need)} = 0$
$FMAX_{S(need)} = 0$

for Patient State Node S_{no}
$E_{S(no)} = 0$ $RMIN_{S(no)} = 0$ $RMAX_{S(no)} = 0$
$DMIN_{S(no)} = 0$ $DMAX_{S(no)} = 9999$ $FMIN_{(no)} = 0$
$FMAX_{S(no)} = 0$

for Patient State Node S_{mild}
$E_{S(mild)} = 0$ $RMIN_{S(mild)} = 0$ $RMAX_{S(mild)} = 0$
$DMIN_{S(mild)} = 0$ $DMAX_{S(mild)} = 9999$ $FMIN_{(mild)} = 0$
$FMAX_{S(mild)} = 0$

for Treatment Node TREQ
$WMIN_{TREQ} = 0$ $WMAX_{TREQ} = 9999$ $T_{TREQ} = 2$
$\beta_{TREQ:S(has)} = .34$ $\beta_{TREQ:S(need)} = .66$ $\alpha_{R(dr):TREQ} = 1$

for Treatment Node VACC
$WMIN_{VACC} = 0$ $WMAX_{VACC} = 9999$ $T_{VACC} = 5$
$\beta_{VACC:S(no)} = .90$ $\beta_{VACC:S(mild)} = .10$ $\alpha_{R(inj):VACC} = 1$
$\alpha_{R(inj):VACC} = 1$

Key to implementing a Patient Flow Model is to choose an objective function that provides a model solution that is in congruence with the decision-making needs of the model user. Guidance in the selection of objective functions is provided in Section 3.6. For this demonstration problem, it is assumed that the model user is interested in minimizing the cost of resources used.[23] To achieve this goal, the objective function is set to:

$$\text{MINIMIZE } [c_{R(dr)} * w_{R(dr)}] + [c_{R(rn)} * w_{R(rn)}] + [c_{R(vac)} * w_{R(vac)}]$$

The formal specification of the Patient Flow Model requires that a number of conditions be met while seeking to achieve the objective function. The conditions applicable to each node in the network were presented in Section 3.3, and are restated here in the context of the Vaccination example. The objective function must be achieved subject to:

$$RMIN_{S(closed)} \leq r_{S(closed)} \leq RMAX_{S(closed)}$$
$$DMIN_{S(closed)} \leq d_{S(closed)} \leq DMAX_{S(closed)}$$
$$FMIN_{S(closed)} \leq f_{S(closed)} \leq FMAX_{S(closed)}$$
$$r_{S(closed)} + E_{S(closed)} - d_{S(closed)} - x_{S(closed):TREQ} - f_{S(closed)} = 0$$

$$RMIN_{S(has)} \leq r_{S(has)} \leq RMAX_{S(has)}$$
$$DMIN_{S(has)} \leq d_{S(has)} \leq DMAX_{S(has)}$$
$$FMIN_{S(has)} \leq f_{S(has)} \leq FMAX_{S(has)}$$
$$r_{S(has)} + E_{S(has)} + y_{TREQ:S(has)} - d_{S(has)} - f_{S(has)} = 0$$
$$y_{TREQ:S(has)} = [\beta_{TREQ:S(has)} * w_{TREQ}]$$

$$RMIN_{S(need)} \leq r_{S(need)} \leq RMAX_{S(need)}$$
$$DMIN_{S(need)} \leq d_{S(need)} \leq DMAX_{S(need)}$$
$$FMIN_{S(need)} \leq f_{S(need)} \leq FMAX_{S(need)}$$
$$r_{S(need)} + E_{S(need)} + y_{TREQ:S(need)} - d_{S(need)} - x_{S(need):VACC} - f_{S(need)} = 0$$
$$y_{TREQ:S(need)} = [\beta_{TREQ:S(need)} = .66 * w_{TREQ}]$$

$$RMIN_{S(no)} \leq r_{S(no)} \leq RMAX_{S(no)}$$
$$DMIN_{S(no)} \leq d_{S(no)} \leq DMAX_{S(no)}$$
$$FMIN_{S(no)} \leq f_{S(no)} \leq FMAX_{S(no)}$$

---

[23] Note that there is choice in this model with respect to whether a PHYSICIAN or a NURSE will act as the care provider for the VACCINATE Treatment. The physician and nurse have different acquisition costs, and are consumed in different quantities. Selecting this objective function will cause the model to use and exhaust the least expensive Resource first, before moving on to consume the more expensive resource should additional Treatments still need to be performed.

$$r_{S(no)} + E_{S(no)} + y_{VACC:S(no)} - d_{S(no)} - f_{S(no)} = 0$$
$$y_{VACC:S(no)} = [\beta_{VACC:S(no)} * w_{VACC}]$$

$$RMIN_{S(mild)} \leq r_{S(mild)} \leq RMAX_{S(mild)}$$
$$DMIN_{S(mild)} \leq d_{S(mild)} \leq DMAX_{S(mild)}$$
$$FMIN_{S(mild)} \leq f_{S(mild)} \leq FMAX_{S(mild)}$$
$$r_{S(mild)} + E_{S(mild)} + y_{VACC:S(mild)} - d_{S(mild)} - f_{S(mild)} = 0$$
$$y_{VACC:S(mild)} = [\beta_{VACC:S(mild)} * w_{VACC}]$$

$$c_{R(dr)} = A_{R(dr)} \div Q_{R(dr)}$$
$$c_{R(rn)} = A_{R(rn)} \div Q_{R(rn)}$$
$$c_{R(vac)} = A_{R(vac)} \div Q_{R(vac)}$$

$$z_{P(inj):VACC} = [\alpha_{VACC:P(inj)} * w_{VACC}]$$
$$z_{P(care):VACC} = [\alpha_{VACC:P(care)} * w_{VACC}]$$
$$z_{R(vac):P(inj)} = [w_{P(inj)} \div \alpha_{P(inj):R(vac)}]$$
$$z_{R(rn):P(inj)} = [w_{P(inj)} \div \alpha_{P(inj):R(rn)}]$$
$$z_{R(rn):P(care)} = [w_{P(care)} \div \alpha_{P(care):R(rn)}]$$
$$z_{R(dr):P(care)} = [w_{P(care)} \div \alpha_{P(care):R(dr)}]$$
$$z_{R(dr):TREQ} = [w_{TREQ} \div \alpha_{TREQ:R(dr)}]$$

$$w_{P(care)} = [z_{P(care):R(dr)} \div \alpha_{P(care):R(dr)}] + [z_{P(care):R(rn)} \div \alpha_{P(care):R(rn)}]$$
$$w_{P(inj)} = z_{VACC:P(care)}$$

$$w_{R(vac)} = [w_{P(inj)} \div \alpha_{P(inj):R(vac)}]$$
$$w_{R(rn)} = [w_{P(inj)} \div \alpha_{P(inj):R(rn)}] + [w_{P(care)} \div \alpha_{P(care):R(rn)}]$$
$$w_{TREQ} = x_{S(closed):TREQ}$$
$$w_{VACC} = x_{S(need):VACC}$$

The vaccination example is a real but relatively trivial Patient Flow Model problem. Formally specifying the model, however, is not a trivial task. Fortunately, the interface chosen to develop Patient Flow Models as a part of this research frees the user from needing to specify Patient Flow Model problems in such a formal manner. Notwithstanding this point, it is important to recognise that the constraints and relationships portrayed in the vaccination example are exactly the same as those which exist in all Patient Flow Model problems.

3.6 Choices in Selecting Objective Functions

This chapter provides a detailed explanation of the process by which Patient Flow Models are defined. A strength of the Patient Flow Model is that the functional specifications of the model are completely independent of the solution engine chosen to operationalise the model. In fact, for some users, the process of developing Patient Flow Model network diagrams is valuable in itself. A Patient Flow Model network provides information that can be used to better understand patient flows and resource consumption patterns. Patient Flow Model network diagrams can also serve as a useful aid during information system development initiatives.

For many users, however, the true benefit of the Patient Flow Model approach to problem specification will come from being able to use mathematical programming techniques to operationalise Patient Flow Model networks. This requires the specification of an appropriate objective function.

Objective functions used to demonstrate the functionality of the model in this research are largely single-function objectives. Maximizing the number of patients treated, minimizing the value of unused resources, and minimizing patient length of stay are all examples of single-function objectives. Single-function objectives facilitate understanding of the model and allow the use of cursory examination to ensure that models behave as expected.[24]

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[24] In fact, although multiple objective functions are not used, multiple objectives are achieved in the demonstration models by restating some objectives as constraints. For example, in research models where the objective function was to minimize unused resource costs, a constraint requiring the number of patients separated to equal the number of patients admitted was added. This ensured the model did not attempt to save costs by not treating some patients.

3.6.1 Multiobjective Linear Programming

In clinical applications, it is common for multiple (and sometimes conflicting) objectives to exist. For example, a hospital might want to maximize the number of patients treated *while at the same time* minimizing operating room overtime.[25] Problems of this type are easily handled because the design of the Patient Flow Model is completely independent of the solution engine chosen to operationalise the model. Multiobjective linear programming techniques can be used. The user simply needs to ensure that the solution engine chosen to operationalise the model has the required functionality.

Multiobjective linear programming techniques can be used to assign weightings to multiple objectives.[26] Alternatively, priorities can be assigned to different objectives. For example, overriding priority might be given to the objective of treating as many patients as possible. The solution engine can be used to find a feasible region in which the maximum number of patients is treated. The model is then solved a second time, holding this value constant, while exploring the feasible region for the lower priority objective(s). (In this case, the lower priority objective is minimizing the use of operating room overtime.)

[25] These are potentially conflicting objective functions because the objective of treating additional patients can be easily achieved by using additional operating room time.

[26] Care must be taken when specifying multiple objective functions when weighting is to be used. All objectives must be stated as either maximisation's or minimisation's, and should be of the same order of magnitude.

3.6.2 Goal Programming

Goal programming techniques can also be used with the Patient Flow Model. Unlike the multiobjective function approach where the decision-maker seeks to find a solution that has only a broadly defined target (e.g., maximize the number of patients treated), goal programming allows the decision-maker to set a specific target for each objective function. For example, hospitals restructuring under Ontario Health Services Restructuring Commission guidelines [HSRC, 1997a] are required to achieve an occupancy rate for alternate level of care (ALOC) patients[27] of as close to 0% as possible. Hospitals are also trying to achieve a bed utilization target of as close to 95% as possible. Instead of specifying hard constraint requiring 95% bed utilization, with an ALOC rate of 0%, goal programming is used to restate the objective functions to minimize the deviation from 95% occupancy and 0% ALOC. This makes both the bed utilization and ALOC objectives soft constraints. Weighed objective and absolute priority approaches can also be used to solve linear programming models when the objective functions are specified using a goal programming approach.

Thus, the process by which the Patient Flow Model is operationalised is extremely flexible. Users are free to select whatever objective function(s) best meets their particular decision-making requirements, and in doing so, are able to exploit the powerful underlying design of the Patient Flow Model.

[27] Patients whose diagnosis does not warrant inpatient admission to an acute care facility, and have therefore been admitted inappropriately.

3.6.3 Practical Examples of Appropriate Objective Functions

In Section 1.3.2, a variety of questions suitable for study using the Patient Flow Model were presented. Addressing these questions requires not only that a suitable Patient Flow Model be available (i.e., that a model designer has already captured the domain of interest in a Patient Flow Model defined format), but also that the user take actions to populate the model and select an appropriate objective function.

To illustrate how these steps can be achieved, the operational and financial issues first raised in Section 1.3.2 are reintroduced here in Table 3.6A. For each question, action required by the model user is presented, together with a suggestion for an objective function that will result in the Patient Flow Model generating information to address the question of interest.

Table 3.6A

Addressing a Variety of Operational and Financial Questions Using the Patient Flow Model

Question of Interest	Action Required by Model User	Appropriate Objective Function Choice(s)
How many additional patients can be treated as a result of adding staff on a ward.	Increase constraint on Supply of *staff* Resource	Maximize separations in allowable exit states.
Will a new treatment protocol affect the average length of stay?	Add new protocol to the model definition. (Action to be taken by model designer.)	Minimize total planned time.
What resource shortages will limit the ability to handle an expected level of patient encounters?	Load model with expected patient encounter data.	Maximize separations in allowable exit states. Examine broken resource availability constraints.
What is the cost of treating a particular group of patients?	Identify clinical path of interest. Run model and sum (cost * occurrences) for each Treatment on the path.	Maximize separations in allowable exit states.
What is the financial impact of acquiring a new diagnostic tool?	Have model designer add the specifications for the new diagnostic tool. Run model with expected patient loading.	Maximize separations in allowable exit states.
Create budget & planning documents.	Run model with expected patient loading and resource availability profile.	Set budgeted surplus equal to zero. (Or to other value as required.)

3.7 Summary of Clinical Dimension Modelling Decisions

While the components used to define a Patient Flow Model remain the same no matter what the modelling environment, this chapter has shown that model designers must nonetheless resolve a number of issues regarding how best to model the problem domain of interest. These issues are summarized in Table 3.7A.

Table 3.7A

Clinical Modelling Issues

Issue	Discussion	Chapter/Section
Should exit arcs from Patient State Nodes be constrained?	Constrain exit arcs from Patient State Nodes in order to create a descriptive model. When unconstrained, the model operates in a normative manner.	Section 3.3.1. Page 58.
Should Treatment Acquisition factors be used?	These are rarely required. Use only when it is necessary to pre-specify the makeup of the patients flowing into a Treatment.	Section 3.3.2. Page 64.
How should clinical pathways be identified?	Key to the validity of any Patient Flow Model is the appropriateness of the allowable clinical pathways.	Section 3.3.2. Page 65. A discussion of this topic is also provided in Section 5.1 where the process used to develop the demonstration models used in this research is presented.
What degree of abstraction should be used in the portrayal of the clinical dimension?		See Section 5.1.2.
What guidance can be provided in identifying Treatments and their related flow patterns?	Four types of Treatments can be modelled using the Patient Flow Model. Each represents a stage in the Treatment process.	Section 3.3.3. See page 70

3.8 Conclusion

This chapter introduced the structure and functionality of the elements that together comprise the Patient Flow Model. The Patient Flow Model is shown to be a powerful network model that is built using four types of nodes. These nodes are Patient State Nodes, Treatment Nodes, Resource Nodes and Package Nodes.

Nodes are connected by pathways. Clinical Pathways are linkages followed by patients as they move from a state of poor health toward a state of better health. Resource Pathways describe routes followed by Resources as they are used in the treatment process. The characteristics and behaviour of each node in the Patient Flow Model was discussed and the notation used to symbolically represent the model was introduced.

The following chapter (Chapter 4) extends the discussion of the Patient Flow Model by introducing the means by which the model generates Resource use and cost information. Chapter Five then combines the material introduced in Chapters Three and Four to demonstrate how the Patient Flow Model is operationalised.

Chapter 4
The Resource Dimension:
Tracking Costs & Resource Utilization

4.0 Overview

The previous chapter developed the conceptual foundation of the Patient Flow Model and focused attention on issues related to the modelling of patients and their interaction with a healthcare facility. This chapter extends the discussion by demonstrating how information on resource utilization and treatment cost is determined by the Patient Flow Model.

The Patient Flow Model uses an activity-based approach to establish the relationship between patients and the resources used when providing care. A simple example is presented early in this chapter to illustrate the difference between activity-based costing and the traditional two-stage cost allocation process currently used by most Canadian hospitals. The balance of the chapter then extends this discussion by demonstrating how the Patient Flow Model addresses specific costing and resource utilization issues.

Thus, the focus of this chapter is on the *resource dimension* of the Patient Flow Model. The focus of the previous chapter was on the *clinical dimension*. *Treatments* provide the vital link between the resource dimension and the clinical dimension of the model. The following concepts are introduced and developed in this chapter:

- how a *resource network* is used to capture information on the resources and non-Treatment activities required to sustain the treatment of patients;
- how the Patient Flow Model distinguishes between resources that are consumed as they are used and those which remain relatively unchanged during the planning period;
- how unused capacity costs are recognized;
- how the existing MIS Guideline chart of account codes are incorporated into the Patient Flow Model;
- how aggregation and disaggregation is used to hide or expose detail in the resource dimension; and
- how both bottom-up or top-down data collection processes can be accommodated by the Patient Flow Model.

The information contained in this chapter, when combined with the information presented in the Chapter Four, provides the complete formal specification of the Patient Flow Model. The subsequent chapter illustrates how formally specified models are developed and implemented.

4.1 Mapping the Patient Flow Model into the Activity-Based Costing Paradigm

Activity-based costing is a methodology that measures the cost of activities, resources and cost objects; assigns resources to activities and activities to cost objects based on their use; and recognizes the causal relationships of cost drivers to activities[1] [Raffish and Turney, 1991].

What distinguishes activity-based costing from traditional costing methods is that activity-based costing is based on the premise that *activities* cause resources to be consumed, and in doing so, for costs to be incurred. In contrast, traditional costing methodologies assume that producing a product, or providing a service, causes costs to be incurred. As a result, products produced in high volumes usually attract proportionately larger amounts of overhead than products produced in smaller volumes because *it is assumed* that the product produced in large volumes must be responsible for creating larger amounts of overhead.[2]

Research during the 1970s demonstrated that this is not always the case (see for example, Cooper and Weiss [1985]). In fact, quite the opposite may be true. Low volume products produced in small batches may actually consume proportionally more overhead than their high volume counterparts. A renewed interest in alternative methods by which overhead costs can be associated with products was kindled [Cooper and Kaplan, 1988; Swenson, 1985].

One of these alternative methods is activity-based costing. Activity-based costing is based on the premise that the activities an organization engages in (such as issuing a purchase order,

---

1 Activity-based management adds the ability to measure the performance attributes.

2 Although some firms recognise that high volume product lines may not actually consume proportionately more overhead than lower volume product lines, attaching overhead to products based on volume is often still used because it is felt that the higher volume products have a greater ability to bear overhead than lower volume product lines.

calibrating equipment, cooking a meal) cause resources to be consumed (such as labour, chemicals, food, etc.), and that these activities are only performed when there is a need to manufacture a product or provide a service. Thus, under activity-based costing, products (services) attract direct and indirect costs based on the actual demand for organizational activity that the product creates, and not based on the volume of the product produced.[3]

The Patient Flow Model subscribes to the activity-based costing paradigm. The model recognizes that patients do not (by themselves) cause costs to be incurred. It is the process of providing care for patients that causes hospitals to incur costs. Consider (in the extreme) that patients sitting in a hospital waiting room have no "cost" to the hospital. Only once treatment begins are costs incurred. This is because it is the *treatment* of patients that causes *resources* to be consumed (and in doing so, causes costs to be recognized.) Treatments, therefore, are activities in healthcare settings which help explain the link between resources and cost objects (such as patients.)

Just as *activities* are the focus of the costing process in activity-based costing, *Treatments* (and the underlying activities required to support Treatments) form the focus of the activity-based costing methodology used in the Patient Flow Model. The *resource-activity-cost object* hierarchy used in activity-based costing [Turney, 1991] is analogous to the *resource-treatment-patient* hierarchy used in the Patient Flow Model (PFM). This parallelism provides a solid structural foundation for using the Patient Flow Model to identify, measure, and report costs.

---

[3] It may be very difficult to trace some types of indirect costs (e.g., the salary of the Chief Executive Officer) to a specific product or service, even when using activity-based costing. When a cause and effect relationship cannot be established between the consumption of a resource and the production of a product/service, attaching the cost to the product/service becomes an arbitrary exercise and should be avoided for management decision-making purposes [Cooper and Kaplan, 1991]. (Full absorption costing has merits for financial accounting and external reporting purposes.)

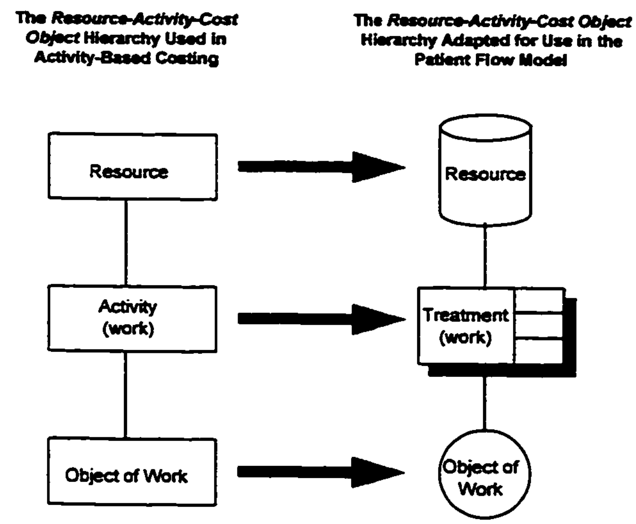

Figure 4.1A: Mapping ABC Terminology to PFM Terminology

In activity-based costing, cost flows terminate at an *object of work* An object of work is any customer, service or unit for which a separate cost determination is required. The most common objects of work in the Patient Flow Model are individual patients, although physicians, programs (e.g., oncology), and groups of patients with similar treatment profiles (such as patients belonging to the same CMG®[4]) can also be considered to be objects of work. The Patient Flow Model is able to generate cost information for a wide variety of cost objects.

Later extensions to activity-based costing have included the ability to explicitly recognize the cost of unused capacity [Cooper and Kaplan, 1992], and the ability to classify costs according to their behaviour using a four level hierarchy [Cooper and Kaplan, 1991]. These extensions are also incorporated into the Patient Flow Model and are developed in subsequent sections.

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[4] A CMG® (Case Mix Group) is a patient classification system used by Canadian hospitals to group acute care inpatients with similar clinical and resource utilization characteristics. Examples of CMGs include Major Eye Infection, Age > 65 (CMG 60) and Caesarean Delivery (CMG 604) [CIHI, 1994].

4.2 Traditional versus Activity-Based Cost Determination

The Patient Flow Model uses an activity-based approach to determine cost information. The following examples show the effect of the costing methodology on the resulting cost information. Data used to develop cost figures using the traditional two-stage cost determination process is recast in a subsequent example using an activity-based approach to cost determination. A discussion of the assumptions implicit in the traditional two-stage approach[5] is also provided.

4.2.1 Traditional Two Stage Cost Generation - An Example

Assume a hospital provides surgery through both an in-patient unit and an outpatient unit. Three service departments (housekeeping, patient transport and accounts payable) provide support to the in-patient and out-patient units and each service department incurred exactly the same costs during the past period.

---

5 The two-stage approach with a single second stage cost driver (direct labour) is the costing methodology currently used by Canadian hospitals.

Service Department	
Housekeeping	
Costs Incurred	$60,000.
Costs are Allocated Using	weighted square feet[6]
Patient Transport	
Costs Incurred	$60,000.
Costs are Allocated Using	dept total costs
Accounts Payable	
Costs Incurred	$60,000.
Costs are Allocated Using	dept total costs

The inpatient and outpatient units differ in a number of respects, including the number of patients treated, and the amount space each occupies in the hospital. This data is provided below.

Unit Details (Data from Previous Operating Period)	
Inpatient Surgical Unit	
Nurse Hours (pd at $20/hr)	2000
Weighted Square Feet Occupied	40000
Number of Patients Treated	200
Nursing Hours per Patient	10
Department Budget	$150,000.
Outpatient Surgical Unit	
Nurse Hours (pd at $20/hr)	5000
Weighted Square Feet Occupied	5000
Number of Patients Treated	1000
Nursing Hours per Patient	5
Department Budget	$135,000.

The conventional two-stage cost allocation process moves costs from each of the service departments (housekeeping, patient transport, and accounts payable) to the patient care units

6 The *MIS Guidelines* apply a weighting factor to building square feet to adjust for the difference in effort required to provide housekeeping services in areas of similar size, but with different housekeeping requirements. (e.g., A surgical theatre has a higher weighting than a ward room.)

(inpatient and outpatient surgery) using a first stage driver.[7] In this case, the first stage driver is the proportionate share of occupied building space for housekeeping services and the proportionate share of total hospital costs for Accounts Payable and Patient Transport Costs. Nursing is treated as a direct cost.

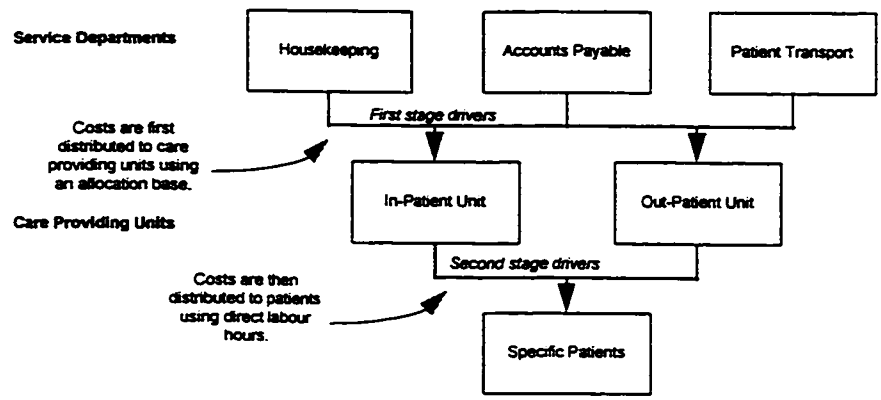

Figure 4.2A: The Conventional Two-Stage Cost Allocation Process

After grouping costs by unit, the cost per direct labour hour is calculated by dividing the total costs accumulated by the number of hours of nursing care provided by the unit. The resulting value (which is in effect, a fully burdened direct labour hour wage) is then multiplied by the number of hours of nursing care each patient received to determine the cost per patient. The calculations which follow suggest that it costs 4.9 times as much to provide surgery on an inpatient basis than it does on an outpatient basis.

7 The costing methodology used by Canadian hospitals uses reciprocal costing to redistribute the service department cost pool balances to adjust for services provided between service departments before allocating costs to absorbing cost centres.

Patient Costs by Program - Direct & Indirect

Inpatient Surgical Unit	
Costs Incurred Directly by Unit	
Nurse Hours (2000hr @ $20/hr)	$40,000.
Costs Allocated to Unit by Transient Cost Centers	
Housekeeping (40000/45000 * $60k)	53,330.
Patient Transport ($150/$285 * $60k)	31,580.
Accounts Payable ($150/$285 * $60k)	31,580.
Total Accumulated by Inpatient Surgical	$156,490.
Therefore...	
Cost per Direct Labour Hour (2000 hrs)	$78.
Cost per Patient for Inpatient Surgery	$780.
(based on data of 10 Nursing Hrs per Patient)	
Outpatient Surgical Unit	
Costs Incurred Directly by Unit	
Nurse Hours (5000hr @ $20/hr)	$100,000.
Costs Allocated to Unit by Transient Cost Centers	
Housekeeping (5000/45000 * $60k)	6,670.
Patient Transport ($135/$285 * $60k)	28,420.
Accounts Payable ($135/$285 * $60k)	28,420.
Total Accumulated by Outpatient Surgical	$163,510.
Therefore...	
Cost per Direct Labour Hour (5000hrs)	$33.
Cost per Patient for Outpatient Surgery	$165.
(based on data of 5 Nursing Hours per Patient)	

To the extent that the square feet of building space occupied by each program is representative of the amount of housekeeping services used, and the proportionate share of departmental budget is representative of the amount of patient transport and accounts payable services used by each functional centre, the costs allocated to each surgical unit are probably reasonable. However, should any of the proxies for the effort demanded by the surgical unit of the service departments *not be* representative of the actual effort used, cost information derived as a result of the allocation is suspect.

4.2.2 Assumptions Implicit in the Two Stage Costing Model

Using direct labour hours to distribute costs other than direct labour requires that four assumptions be made regarding the behaviour of the non-labour costs. These assumptions are:

1. *An individual patient's cost function is linear.*

   The use of non-labour resources must be proportional to a patient's use of the labour resource. For example, if a patient requires 2 hours of nursing and uses $50 worth of drugs, then the same patient *must* use $100 worth of drugs after receiving 4 hours of nursing.

2. *Patients treated in the same functional centre have the same cost function.*

   Two patients requiring the same amount of labour must use the same amount of non-labour resources. In other words, if Patient A requires two hours of nursing and uses $50 worth of drugs, then Patient B who requires two hours of nursing *must* also have used $50 worth of drugs.

3. *Direct labour hours are the best proxy to explain the use of non-labour resources.*

   It is assumed that the use of care providing labour (e.g., nursing labour) best explains a patient's use of all other indirect costs required to provide care. These costs include housekeeping services, laundry, meals, etc.

4. *The workload systems used to record data on the amount of direct labour used by patients are both inclusive and accurate.*

   Workload measurement systems are used to capture the total number of direct labour hours used to provide patient care. This number is used as a denominator in the calculation of the fully burdened cost per direct labour hour. To the extent that the measured workload fails to identify worked output, or captures this worked output incorrectly, all cost determinations made using the burdened direct labour hour value are corrupted.

There is currently no widely reported empirical proof to support or refute the validity of these assumptions in healthcare settings, however, research in other sectors has called into question the ability to use direct labour hours as a proxy for the allocation of indirect costs [Cooper, 1987; Kaplan and Johnson, 1987]. Activity-based costing has been advocated as a technique that can be used to help overcome the costing distortions that can be caused by a single, second stage cost driver [Cooper, 1987; 1988a; 1989b].

When using activity-based costing, the cost of resources consumed (such as nurses, linens, clerks) is first associated with activities (such as injecting a needle, making a bed, or being admitted to the hospital) that require the resource in order to be performed. Once the cost of performing activities is known, the next step is to determine which patients ("objects of work" in the activity-based costing vernacular) took part in which activities during their episode in the hospital. The cost of providing care to a patient can be determined by summing the value of the series of activities in which the patient participated. As will be seen in the example which follows, the cost to provide care can appear to vary markedly based on whether the cost is calculated using the traditional approach or an activity-driven approach. The apparent difference in cost results from the ability to relax assumptions presented in this section.

4.2.3 The Activity-Based Approach - An Example

To contrast the activity-driven approach to cost determination with the traditional approach to cost determination, the example developed for traditional costing is restated here in activity-based terms. *In both examples the number of hours of nursing time, the amount paid to nurses and the cost of all resources used are identical.* In this example, however, cost flows are restated in terms of activities and resources, and an activity-based approach to associating resource costs with patients is used.

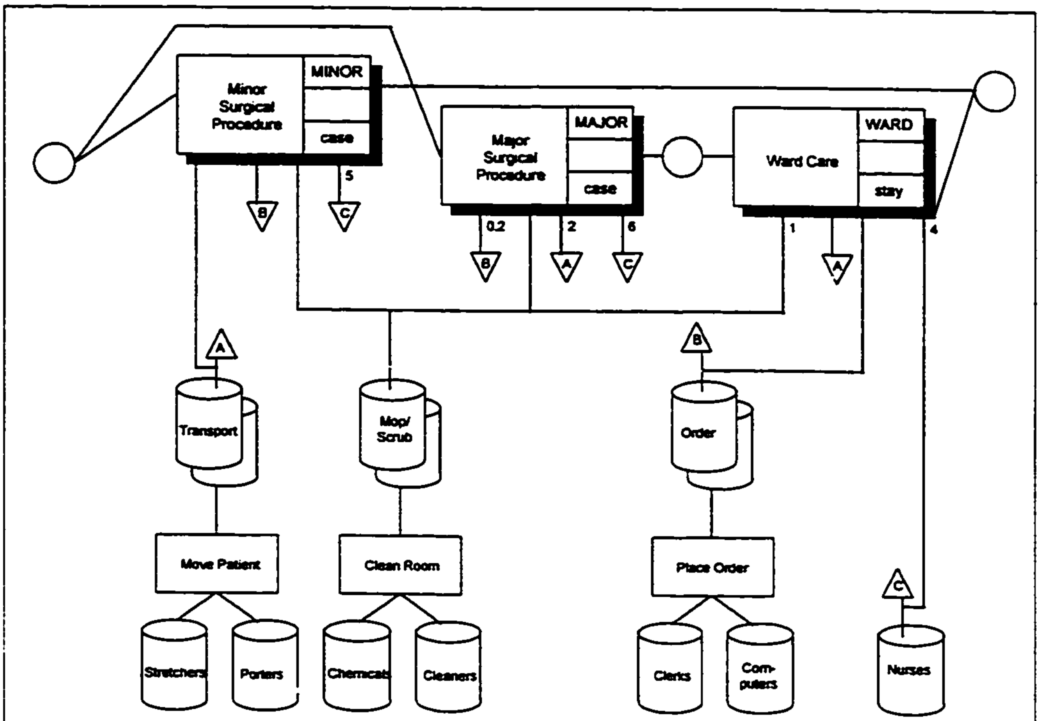

Figure 4.2B:
Patient Flow Model for the Inpatient & Outpatient Example

The cost objective also remains unchanged – to determine the cost of providing an inpatient surgical procedure and outpatient surgical procedures. A Patient Flow Model is shown for the matching scenario in Figure 4.2B.[8]

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8 An optional model component called *non-Treatment activities* is shown in Figure 4.2B. Non-Treatment activities are represented as rectangles in the Resource Network. (Examples in Figure 4.2B are MOVE PATIENT, CLEAN ROOM and PLACE ORDER. Non-Treatment activities are described in Section 4.3.

Treatments Performed
(No change from previous example)

Minor Surgical Procedure	1000 cases
Major Surgical Procedure	200 cases
Ward Care	200 stays

Resources Available
(Value of Resources Used is Identical to Amounts in Previous Example)

Chemicals/Cleaners (used to perform the activity "Clean Room")

Resource Driver	Moppings/Scrubbings
Value of Resources Used	$60,000.
Number of Times Activity is Performed	1400
Value of Resource Package	$42.86

Stretchers/Porters (used to perform the activity "Move Patient")

Resource Driver	Transport Patient
Value of Resources Used	$60,000.
Number of Times Activity is Performed	1200
Value of Resource Package	$50.00

Clerks/Computers (used to perform the activity "Place Order")

Resource Driver	Place Order
Value of Resources Used	$60,000.
Number of Times Activity is Performed	1240
Value of Resource Package	$48.39

Activities Required to Support Each Treatment & Resources Used

Minor Surgical Procedure	
Nursing (5 pkgs @ $20/hr)	$ 100.00
Transport Patient (1 pkg @ $37.50)	50.00
Mop/Scrub/Sterilize (1 pkg @ $37.50)	42.86
Place Orders (1 pkg @ $57.69)	48.39
	$ 241.25
Major Surgical Procedure	
Nursing (6 pkgs @ $20/hr)	$ 120.00
Transport Patient (2 pkgs @ $50.00)	100.00
Mop/Scrub/Sterilize (1 pkg @ $42.86)	42.86
Place Orders (0.2 pkg @ $48.39)	9.68
	$ 272.54
Ward Care	
Nursing (4 pkgs @ $20/hr)	$ 80.00
Transport Patient (1 pkg @ $50.00)	50.00
Mop/Scrub/Sterilize (1 pkg @ $42.86)	42.86
Place Orders (1 pkg @ $48.39)	48.39
	$ 221.25

Activity-Based Cost of Providing Care

Inpatients		
Activity	Cost to Perform	Extension
Major Procedure	1 @ $272.54	$273.
Ward Care	1 @ $221.25	221.
Cost of Inpatient Care		$494.
Outpatients		
Activity	Cost to Perform	Extension
Minor Procedure	1 @ $241.25	$241.
Cost of Outpatient Care		$241.

Traditional costing methods show the cost of providing care to inpatients to be almost five times greater than the cost of providing care to outpatients. ($780 vs. $160) In contrast, the activity-based approach to determining the cost of providing care confirms that providing inpatient care is indeed more expensive than providing the same care on an outpatient basis, but the magnitude of the difference is far less than originally determined. ($494 vs. $241)

Comparison of Conventional and Activity-Based Cost Determination

	"Cost" determined using 2 stage process	*"Cost" determined by ABC as used in the Patient Flow Model*
Inpatient Care	$780.	$494.
Outpatient Care	$160.	$241.
Amount by which inpatient care appears to exceed the cost of outpatient care	4.9x	2.0x

The difference in costs between those calculated using conventional approaches to cost determination and those calculated using the activity-driven approach employed by the Patient Flow Model results from the use of drivers by the Patient Flow Model that better explain the reason resources (particularly resources consumed in an indirect manner) are used by patients.

4.3 The Resource Dimension

The focus of the Resource Dimension is on the quantity and cost of resources (such as equipment, labour and supplies) used to provide care. *All* cost information generated by the Patient Flow Model is derived from data stored in Resource Nodes. A method identical to that used to balance the flow of patients through Treatment and Patient State nodes is also used to balance the flow of Resources as Resources move from their origin in Resource Nodes to ultimately being associated with specific patients.

4.3.1 The Resource Network

A *resource network* is used to manage the possible paths a Resource can follow as it moves from its origin in a Resource Node to finally being associated with a Treatment. The Resource Network consists of Resources, non-Treatment activities and Resource Packages. The resource network captures details on the full range of Resources (such as labour, materials, equipment, and facilities) available in the hospital. Some Resources are used exclusively by only one Treatment, while other Resources are used by a number of Treatments. (The latter is more common.) A strength of the Patient Flow Model is that the model can solve problems in which Resources are not only shared, but also may have finite availabilities.[9]

Resource Packages have a cost (equal to the sum of the Resources used to assemble the package), and a unit of measurement (e.g., meal), and can assume any of the limit parameters found in Resource Nodes. Limit parameters, however, are rarely needed for Resource Packages as most constraints on the availability and use of Resources exist at the Resource Node level. Resource Nodes always lie at the root of the resource network.

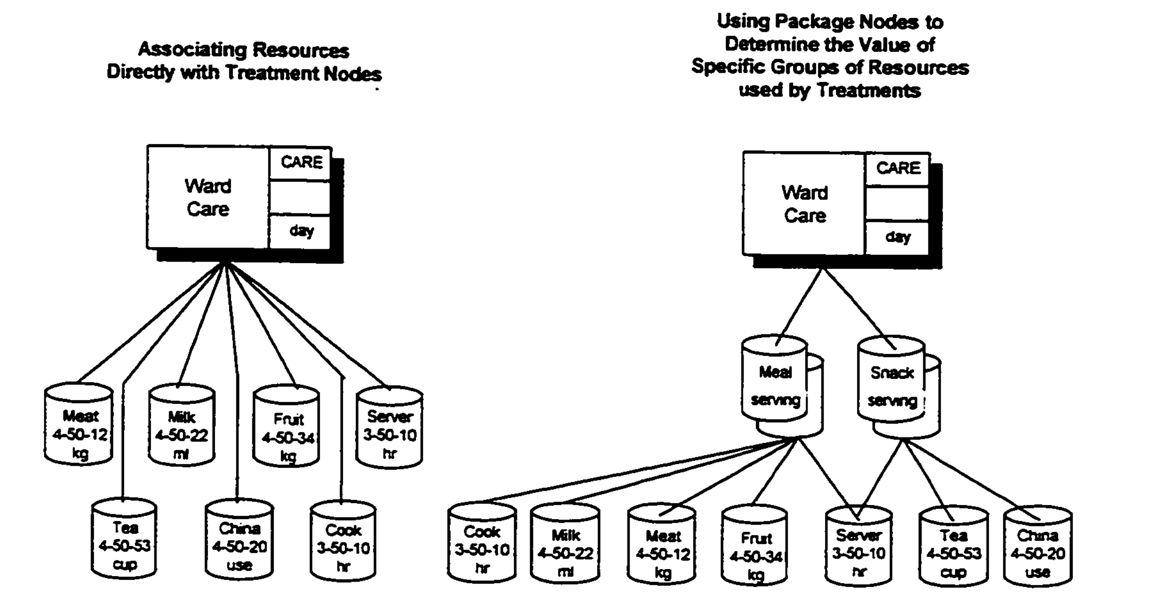

Figure 4.3A
Creating a Resource Hierarchy Using Package Nodes

[9] The objective function chosen when solving a Patient Flow Model determines which Treatments will be favoured when competition for constrained Resources exists.

4.3.2 Non-Treatment Activities

In the earlier discussion of how the elements of the Patient Flow Model map to constructs used in activity-based costing, it was shown that Treatments are *activities* which explain the use of *resources* by *objects of work*. While it is conceptually possible to use the parallelism of *Resource/Treatment/Object of Work* to model the link between every resource and every patient, in real-world settings is extremely difficult to model the multitude of linkages that such a direct relationship requires.

To better explain the relationship between Resources and patients, it is useful to recognize that performing a Treatment usually triggers the need to engage in other activities. For example, the Treatment WARD CARE may require three meals to be cooked, a floor to be scrubbed, and laundry to be washed. Each of these are activities that support the WARD CARE Treatment.

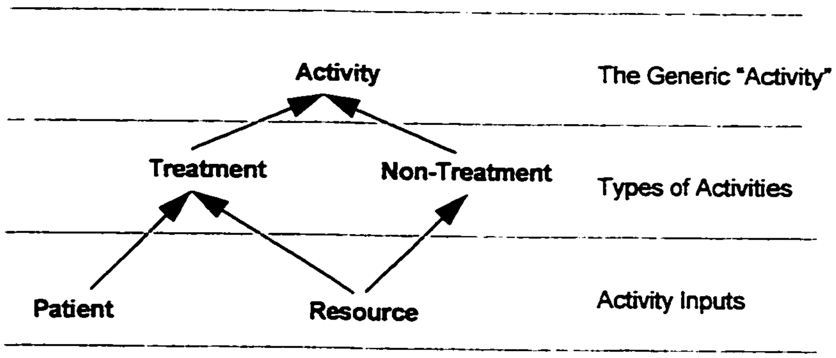

Figure 4.3B
Classifying Activities in the Patient Flow Model

In this research, all activities involving direct patient care are called *Treatments*. (WARD CARE is an example of a Treatment in the previous example.) For ease of distinction, activities not involving direct patient care are called *non-Treatments*.[10] Note that both Treatment activities and non-Treatment activities both consume resources. The distinction is that patients are only involved with Treatment activities. Non-treatment activities are shown as unshaded rectangles in a Patient Flow Model network diagram, and are found only in the Resource Dimension.

The concept of a non-Treatment activity is important to the Patient Flow Model. The non-Treatment activity allows the *Resource/Activity/Object of Work* construct to be respected throughout the model. While the *object of work* for Treatments is usually a patient, the object of work for non-Treatment activities is a collection of Resources that are bundled together to form a *Resource Package*. Resource Packages often act as inputs to subsequent *Resource/Activity/Object of Work* triples.

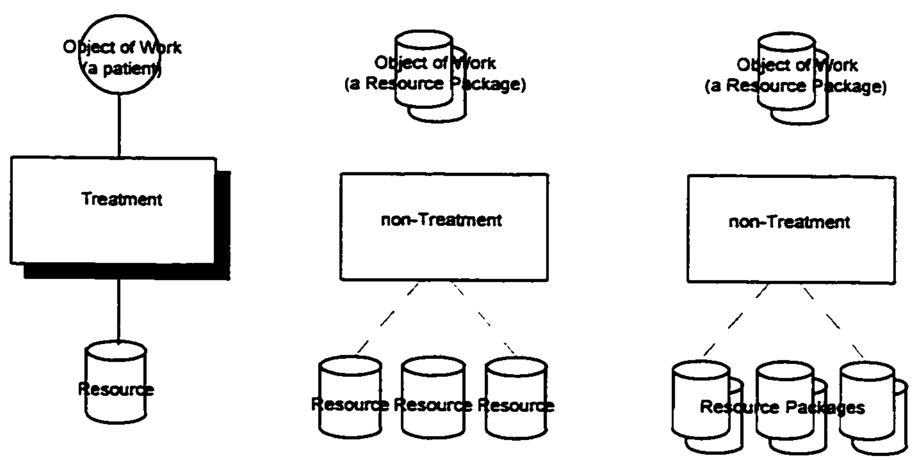

Figure 4.3C
Three Representations of *Resource-Activity-Object of Work* by the Patient Flow Model

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[10] Non-treatments are analogous to support activities in an industrial setting.

Non-treatment activities always involve combining resources into a larger package. For example, the COOK MEAL activity requires the use of resources such as food, a cook's time, kitchen equipment. The output from the COOK MEAL activity is a bundle of resources that have been assembled to create a MEAL. The MEAL is an example of a Resource Package.

4.3.3 Modelling Decisions Regarding the Structure of the Resource Network

In Section 4.3.2 it was shown that non-Treatment activities allow the construct of *Resource/Activity/Object of Work* to be respected throughout the Patient Flow Model. The *object of work* for a non-Treatment activity is always a Resource Package – a bundle of Resources that act as the input to a subsequent *Resource/Activity/Object of Work* triple. The model designer, however, has considerable flexibility to decide how best to structure the Resource Network in order to best match the output generated by the Patient Flow Model to the decision making needs of the model user.

Specifically, the model designer must make three decisions regarding the structure of the Resource Network. These decisions are:

1. deciding whether an activity is best modelled as a Treatment or as a non-Treatment;
2. deciding whether to suppress the explicit representation of non-Treatment Activities or Resource Packages; and
3. deciding on the appropriate level of detail in the Resource Network.

Guidance is offered for each of these decisions, although the overriding consideration in each case must be given to the decision-making needs of the model user. As was stressed in Chapter 3, it is important that the model designer gain an indepth understanding of the types of decisions Patient Flow Model output will be used to support. Only with such an understanding can the model designer ensure that the structure of the Patient Flow Model best meets the model user's requirements.

4.3.4 Distinguishing between Treatment and non-Treatment Activities

Any activity that can be measured in terms of *patients* can be modelled as a Treatment. The guideline used in this study to distinguish between Treatment and non-Treatments activities is to determine whether the activity is either:

- chartable – i.e., as a result of a patient participating in the activity a notation is made on the patient's medical record; or
- the activity is a part of the accepted clinical protocol for the medical condition(s) being modelled.

If either of these conditions are true, the activity is modelled as a Treatment in this research. Modelling chartable interventions as Treatments, and all other activities as non-Treatments, also provides useful separation between the Patient Flow Model's medical domain (which focuses largely on Patient States and Treatments) and the Patient Flow Model's accounting domain (which focuses largely on Resources and Resource Packages.)

4.3.5 Choosing to Suppress Resource Packages or non-Treatment Activities

When a non-Treatment activity has only one output, the one-to-one mapping between the non-Treatment activity and the resulting Resource Package (the non-Treatment activity's *object of work*) provides the model user with an opportunity to simplify the data presentation process. This can be done by suppressing the explicit modelling of either the non-Treatment activity or its matching Resource Package.

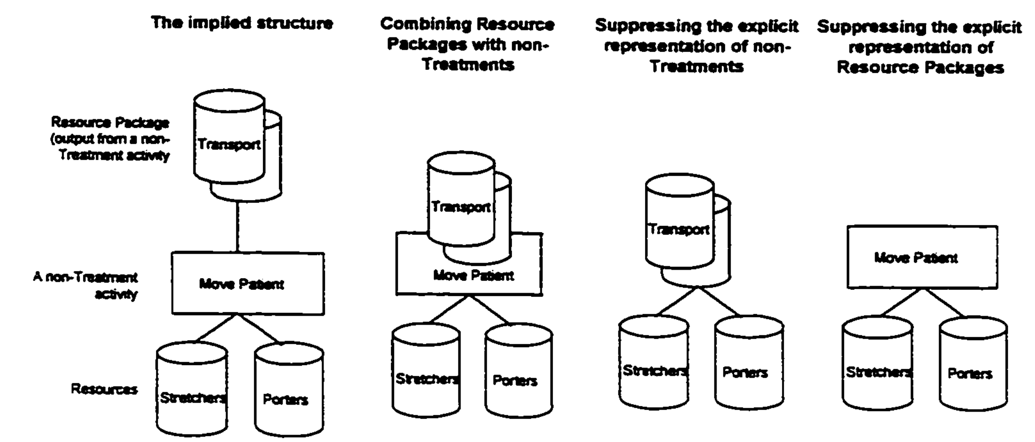

Figure 4.3D
Four Ways to Represent the Same Information in a Patient Flow Model Network Diagram

The decision to focus attention in model presentation on non-Treatment activities or on Resource Packages is guided largely by the process used to collect the data needed to create the model.

1. If activity-based costing data is gathered using a bottom-up approach in which the use of a resource is first apportioned between activities, it is recommended that the presentation of Resource Packages be suppressed. Attention is then focused on the network of interconnected activities.

2. If activity-based costing data is created using a top-down approach in which the resources needed to sustain each treatment are determined using a drill-down approach, it is recommended the representation of non-Treatment activities be

suppressed. This is sometimes called a micro-costing approach. Attention is then focused on the network of interconnected Resource Packages.

These are only guidelines. Conceptually, the Resource Network is always comprised of triples consisting of *Resource/activity/Resource Package*[11]. Choosing the suppress the explicit representation of non-Treatment activities or Resource Packages has no impact on the functionality of the model and serves only to simplify the structure of the Patient Flow Model network diagram for the user. Because a micro-costing approach is used for examples developed in this study, representation of non-Treatment activities is frequently suppressed in Patient Flow Model diagrams presented in this research.

4.3.6 Aggregation & Disaggregation of the Resource Network

In addition to deciding whether to suppress the representation of non-Treatment activities or Resource Packages, the model user also has considerable freedom to decide the degree of disclosure that should be used in the development of the resource network. Aggregation is the process of combining related non-Treatment activities or Resource Packages into a higher level entity. Aggregation is encouraged whenever the information content of the elemental non-Treatment Activities or Resource Packages is not required by the decision-maker. Aggregation simplifies the Resource Network by reducing the number of nodes in the network.

[11] i.e., Resource / Activity / Object of Work

Disaggregation is the decomposition of a non-Treatment activity or Resource Package into subsidiary components. Disaggregation is encouraged whenever the information content of the decomposed elements is of value to the model user.

Aggregation and disaggregation are vertical abstractions in the Patient Flow Model. The concept is patterned closely after the approach to data presentation used in McCarthy's *Resource-Event-Agent (REA)* model [McCarthy, 1982]. Aggregation and disaggregation are similar to the concepts of *compression* and *expansion* which are used in the following chapter to describe the process of refining or expanding the amount of detail shown in Clinical Pathways. (See Section 5.1.2, Step 3)

4.4 Cost Information for Infeasible Solutions Is Not Reported

A feature of the Patient Flow Model is that cost and resource utilization information is only reported by the solution engine if the healthcare facility is able to obtain the Resources necessary to engage in the desired level of activity. Thus, even if all operational constraints are met (such as constraints placed on the number of patients allowed to remain in particular Patient State Nodes), the model will not report a solution unless resource availability constraints are also met. This section discusses the process by which Resource cost information is calculated.

4.4.1 Cost Flows

The Patient Flow Model's ability to balance patient flows entering and leaving Patient State and Treatment Nodes permits the use of linear programming techniques to identify optimal solutions for scenarios posed of the Patient Flow Model. The power of linear programming is also exploited to support the cost determination component of the Patient Flow Model. This is accomplished by ensuring a similar balancing for flows of Resources passing through Resource and Package Nodes.

Patients entering a Treatment Node create a demand for activity. Because it is impossible for a patient to remain in a Treatment Node at the end of a planning horizon,[12] it is necessary for the model to ensure that the Resources necessary to complete a Treatment are available for each patient flowing into a Treatment Node. This is accomplished by having the Treatment Node "push" a request for the Resources it needs to sustain a required level of activity down through the resource network. Once the root nodes of the network are reached, the Patient Flow Model determines if the necessary Resources are available. If the Resources are available, the cost of the Resources needed are "pulled" up from the Resource Node to the Treatment Node. (While being "pulled" up to the Treatment Node, the cost of assembling intermediate Resource Packages is also calculated.) The Patient Flow Model also records consumption information, ensuring that Resources which have already been consumed are not used again in response to a request received from another Treatment Node.

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[12] Patient State Nodes are used to capture information on patients remaining in the hospital at the end of the planning horizon.

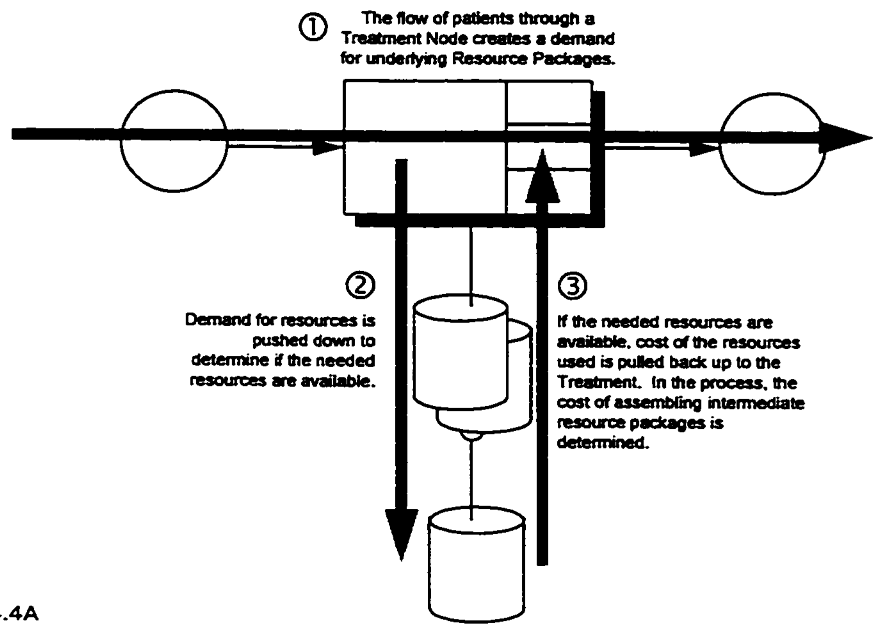

Figure 4.4A
Cost Flows in the Patient Flow Model

There is a balance of flows at each node during the upward flow of Resources. The total quantity of resource units entering a Resource Node or a Package Node equals the quantity of resource units leaving the node. Although balancing is accomplished by maintaining a constant ratio between resource units entering the node and those leaving, this implicitly also leads to a simultaneous balancing of flows based on dollar values. The total value of resources entering a Resource or Package Node always equals the total value of Resources leaving the node.

4.4.2 Costs are Determined After Flows

As described in the previous section, the first step in "solving" a Patient Flow Model is to determine the flow values for all arcs (i.e., pathways) in the network. This is accomplished using linear programming techniques. With flow values for all arcs in hand, the model is then repopulated and a second pass is made to determine cost related information.

One way to imagine the process of attaching costs to patients is to consider Treatments to be *value-added* activities. Instead of considering patients to "cost" the hospital money, patients instead are imagined to increase in value as they pass through each Treatment.

Consider the following example in which a group of patients in the state TETANUS NEEDED have collectively accumulated costs of $5000 during their hospital encounter. During the solution of the model it has been determined that the aggregate cost of providing the VACCINATION Treatment is $1000.

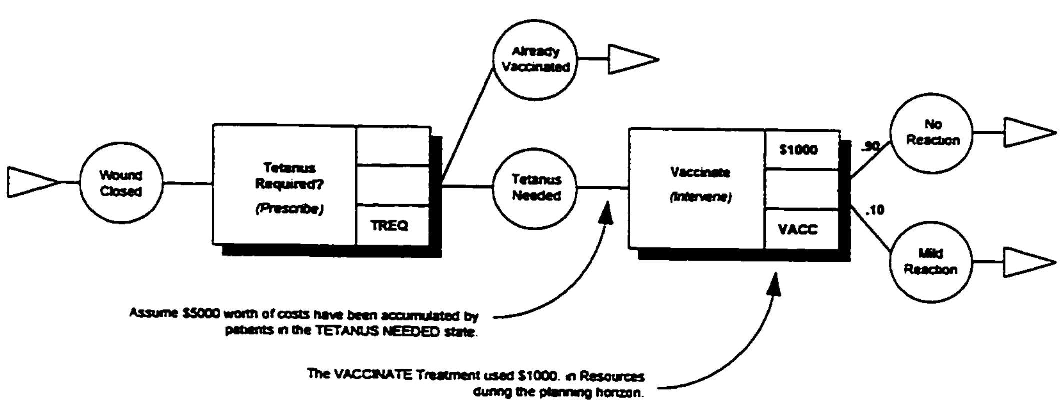

Figure 4.4B
Clinical Flows in the Tetanus Vaccination Example

The accrued "value" of Patients passing through the VACCINATE Treatment is increased by each patient's proportional share of the total cost of providing the Treatment. Thus, the aggregate cost of providing a Treatment follows patients leaving via each exit arc in the same proportion as the Treatment Distribution Factor for that arc. In figure 4.4B, patients emerging in the NO REACTION state are considered to have increased in "value" by $900 in total, while $100 in value will be added to the accumulated "value" of patients emerging in the MILD REACTION state.

This may be situations where this is not the appropriate way in which to accumulate value for patients. Consider an expensive program mounted to detect and treat a high risk illness. It might be decided that all costs associated with the program should follow the patients who are found to have the high risk illness, and that program related costs will be understated if some costs follow patients who are determined not to exhibit the illness, but who made use of resources allocated to the high risk illness program early in their hospital stay. A discussion of how this issue might be resolved is deferred to *Section 6.3.2 – Tracing Cost Flows Leaving Treatments.*

4.5 Issues Related to Measuring Resource Usage

Determining the value of a Resource that should be associated with activities making use of the Resource is influenced by two factors. These factors are discussed in this section.

4.5.1 Persistent and Consumable Resources

Two types of Resources lie at the root of the resource network – *Persistent Resources* and *Consumable Resources*. Both share the same attributes. Persistent and Consumable Resources differ only with respect to the accounting treatment given to the value of unused Resources remaining at the end of the planning horizon.

Consumable Resources disappear as used. Drugs and bandages are representative examples. The key characteristic of a Consumable Resource is that the quantity on-hand of a Consumable Resource is physically depleted each time the Resource is used in an activity. At the end of the planning horizon, unused quantities of a Consumable Resource can be saved and used in a subsequent period. The value of any units of a Consumable Resource left unused at the end of a planning horizon appear on the Balance Sheet as an asset, and have no impact on the cost of providing care. The Patient Flow Model uses the term *Consumable Resource* in lieu of the term *variable cost* to reinforce the important distinction between consumption and spending [Cooper and Kaplan, 1992; CMA, 1996].

Not all Resources disappear as they are used. Some Resources remain relatively unchanged over the course of the planning horizon, even though the Resource may have been used extensively. This type of Resource is called a Persistent Resource. A Persistent Resource is a Resource whose value is temporal. An CT scanner[13] is an example of a Persistent Resource.

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13 An CT scanner (computed tomography scanner) is a diagnostic imaging tool.

Unlike Consumable Resources, the only difference in a Persistent Resource between the beginning and end of a planning horizon is essentially an artificial difference created for accounting purposes. In the case of the CT scanner, the scanner's utility to the hospital remains unchanged even though a period of time has elapsed and the scanner was used by many patients.

Although there is little difference in the CT scanner between the beginning and end of the planning horizon, there is a need for accounting purposes to match the *spending* on the scanner with the *consumption* of the equipment. Accountants do this using the concept of *depreciation*. Depreciating an asset over its useful life ensures that income streams derived from using the asset are appropriately matched with the cost of owing the asset. Persistent Resources are roughly analogous to the conventional accounting concept of *fixed costs*. As was the case with Consumable Resources, a digression from conventional terminology is used to emphasize the distinction between spending (which occurred when the CT was purchased) and consumption (which does not occur until the scanner is used by patients.)

Although the utility of Persistent Resources remains relatively unchanged over the planning horizon, it is still possible to measure the use of a Persistent Resource by associating a unit of measurement with the Resource. For example, a salaried nurse is a Persistent Resource, although the use of the nurse by the hospital can be measured in terms of a resource unit such as hours.

While unused quantities of Consumable Resources can be stored and used in subsequent periods, unused quantities of Persistent Resources cannot be stored and used in subsequent periods. Because of this, the value of a Persistent Resource's closing balance is treated as a period cost.

The difference between the value of Persistent Resource actually used, and the value of the Persistent Resource is treated as a period cost and is called the *cost of unused capacity*.

4.5.2 Recognizing the Cost of Unused Capacity

The Resource Units of a Persistent Resource available for use during the planning horizon represent the Resource's *capacity* to support Treatment and non-Treatment activities. Unlike Consumable Resources however, Resource Units of a Persistent Resource remaining at the end of the planning period cannot be carried forward and used for activities that do not occur until the following planning period. Thus, although these Resource Units have been acquired and paid for by the hospital, their utility is lost to the organization.

Acquiring and paying for Resources that are never used presents an interesting problem from an accounting perspective. The appropriate treatment of such expenses is governed by Generally Accepted Accounting Principles [CICA, 1996]. The value of Resources that have been paid for but never used must be treated as an expense during the planning horizon when the Persistent Resource was acquired. While this is an appropriate treatment of the expense from a financial accounting perspective, the expensing of unused resources can give misleading signals to management.

Consider the following example of two computed tomography imaging units (CT scanners). One machine was purchased by a large metropolitan teaching hospital, the other by a smaller community hospital that acts as the primary care facility for a large but geographically isolated region. Both hospitals provide tertiary care and have a similar capabilities in terms of specialties.

	Large Urban Hospital	Smaller Isolated Hospital
Cost of machine	$1,200,000.	$1,200,000.
Useful Life	6 yrs	6 yrs
Value of the Persistent Resource to recognize each year ($1,200,000 / 6 years)	$200,000.	$200,000.
Number of CT Scans Performed In First Year of Operation	8000	2000
"Cost" per CT Scan (e.g. $200,000/8000)	$25.	$100.

Conventional accounting methods suggest that it costs four times as much to take CT scans in a geographically remote hospital than it does in a large urban hospital. While at one level there is truth to this statement (in that the rural hospital has indeed spent $200,000 to provide 2000 CT scans), in this case the difference is not the result of it costing more to take CT scans in remote areas.[14] Rather, the difference results from a lower level of utilization of the scanner located in the remote region.

Having some capacity of a Persistent Resource available to an organization is what "costs" money, and whether the Persistent Resource is used or not, the full cost of having the capacity available must be reflected in the financial statements for the period. For managerial purposes,

[14] A number of factors might actually contribute to it costing more to take CT scans in geographically remote regions. Staff might be paid an isolation differential, appointments might be longer to accommodate travel needs of patients, contrast media may cost more because of increased shipping costs, etc. In this case, however, it is assumed the cost of the Persistent Resource is not affected by these factors.

however, a tremendous amount of information is lost if the difference between Resources that are paid for and used and those that have been paid for but are never used is not captured in management reports.

The Patient Flow Model recognizes this difference by explicitly recording the *cost of unused capacity*. The cost of unused capacity represents units of a Persistent Resource that have been paid for (or are recognized for accounting purposes as having been paid for) during the planning horizon, but which are never used by Treatments. This follows a concept introduced by Cooper and Kaplan [1992] and is used to provide important signals to management regarding resource utilization.

A more appropriate presentation (for many management decision making purposes) describing the cost of providing CT scanning services is shown on the next page.

	Large Urban Hospital	Smaller Isolated Hospital
Cost of machine	$1,200,000.	$1,200,000.
Useful Life	6 yrs	6 yrs
Number of CT Scans Performed In First Year of Operation	8000	2000
Nominal Capacity of Unit	8000	8000
Cost to Provide Scanning Services	$ 200,000.	$ 50,000.
Cost of Unused Capacity	0.	150,000.
	$200,000.	$200,000.

Explicitly recognizing the cost of unused capacity allows users of financial information to make important decisions. For example, it may be decided that it is worth $150,000 to have CT scanning capabilities available in remote areas of a province. In the absence of this equipment, patients would be extremely inconvenienced (and possibly their health may be endangered) if they needed to be transported to the larger metropolitan area.

Alternatively, it may be decided that the cost of the unused capacity is indeed unacceptable. Specific recognition of unused capacity allows the magnitude of the "overspending" problem to be identified. Closer examination by management may show that the problem is not that the hospital is spending more than others to take CT scans, it just is not taking enough CT scans to justify the large expenditure in equipment that has been made. Under this scenario, managers are given appropriate signals to either seek more patients (possibly by accepting patients from other facilities), or to replace the scanner with a lower priced unit better matched to the hospital's expected level of use.

4.6 The Patient Flow Model is Compatible with the MIS Guidelines

The functional specifications for information systems used in Canadian hospitals are outlined in the MIS Guidelines [1997a]. One component of the MIS Guidelines of particular interest to the Patient Flow Model is the chart of accounts. This is because the general ledgers in all Canadian hospitals are built using the same foundation chart. A standardized chart of accounts, combined with a standardized set of financial definitions permits the comparison of financial results across facilities.

In order to populate the Patient Flow Model with data, a link must be built between the accounting constructs found in the Patient Flow Model (which are largely based on Resources and Treatments) and those used in the general ledger systems found in Canadian hospitals (which are based on the traditional concepts of revenues and expenditures.) The flexibility built into the structure of the MIS chart of accounts together with the Resource-Treatment-Patient hierarchy used by the Patient Flow Model permits this to occur.

4.6.1 Structure of the MIS Chart of Accounts

The MIS chart of accounts is based on a functionally-oriented organizational structure. Within each hospital there are a variety of operating units engaged in providing care directly to patients. A surgical ward, the laboratory and the diagnostic imaging department are all examples of care providing units. Other operating units engage in activities that indirectly support the provision of care. For example, the housekeeping department is responsible for cleaning the surgical ward. Operating units that provide services, whether the service be direct or indirect are called *functional centres* in the MIS Guidelines. Functional centres provide a foundation upon which general ledger codes are built. Functional centres are analogous to cost pools.

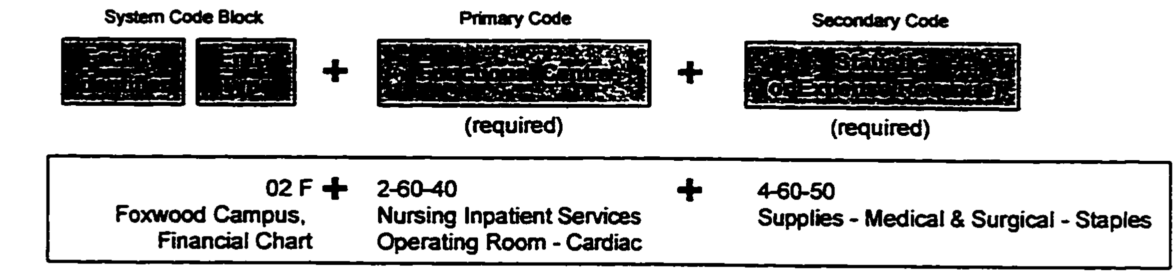

Figure 4.6A
The Three Component Parts of the MIS Chart of Accounts Code

The coding scheme uses a multi-block hierarchical code. The first block identifies the healthcare facility (when a hospital has more than one location) and indicates the type of code appearing in the secondary code block. (i.e., Whether the secondary code block contains a financial ledger code, or a statistical code.) The middle block identifies the functional centre involved in the transaction and is called the *primary code*, while the final code block captures either the nature of the expense/revenue or quantitative data regarding activities within the functional centre. The terminal code block is called the *secondary code.*[15]

4.6.2 Linking Primary Codes to Activity Nodes

The hierarchical block coding scheme allows a level of detail appropriate to the healthcare facility to be selected when discriminating between functional centres and expense/revenue

[15] Because the first code block consists of a code that is constant throughout the complete chart (unless the hospital has multiple facilities within the same corporation), most attention during the transaction recording process is given to selecting appropriate codes for the second and third code blocks. This is why these blocks are referred to as primary and secondary codes.

classifications. This can be seen in the codes used for representative examples drawn from the Nursing Inpatient Services and Administrative/Support Service functional centres.

G/L Code	Description of Functional Centre		
2 00 00	Nursing Inpatient Services		
2 60 00	"	- Operating Room(s)	
2 60 25	"	"	- Dental
2 60 40	"	"	- Cardiac
2 65 00	"	- Post-Anaesthetic Recovery Room(s)	
2 65 40	"	"	- Cardiac Recovery
2 65 60	"	"	- Neurosurgery
1 00 00	Administrative & Support Services		
1 65 00	"	- Plant Maintenance	
1 65 20	"	"	- Grounds
1 65 40	"	"	- Building Maintenance
1 80 00	"	- Registration	
1 80 20	"	"	- Inpatient Registration
1 80 40	"	"	- Outpatient Registration

The coding structure demonstrates how either broad or detailed codes can be assigned for functional centres (i.e., cost pools). It is not expected that any hospital would assign all costs to functional centre codes as broad as 1-00-00 or 2-00-00. Similarly, very few hospitals distinguish between all costs at the most detailed level possible. For example, in a hospital with only one recovery room, it would be difficult to create cost pools for both cardiac patient recovery and neurosurgery recovery. In practice, hospitals are guided by a minimum reporting level requirement set by their Provincial Ministry or Department of Health, and local management reporting needs.

Primary codes specified in the MIS chart of accounts map to activity nodes in the Patient Flow Model. Each activity node (whether a Treatment Node or a non-Treatment node) has an MIS chart primary code as a descriptive attribute. The primary code provides information on the functional centre responsible for providing the activity. The primary code for the Ward Care example developed earlier in this chapter is 2-10-10, indicating that the Ward Care is being provided by a general medical inpatient nursing unit.

4.6.3 Linking Secondary Codes to Patient Flow Model Components

The final component of the general ledger code used in the MIS chart of accounts is the secondary code. Secondary codes describe either the nature of the expense incurred by a functional centre[16], or are used to capture quantitative data regarding levels of activity within a functional centre. An example of the latter is the number of hours worked by staff in the centre. The MIS Guidelines refer to quantitative, non-financial data as *statistical data*. A *statistical chart of accounts* is used to classify quantitative, non-financial data. A *financial secondary chart of accounts* is used to select secondary codes to classify expenses.

Representative financial secondary codes are shown below.

Secondary G/L Code (Financial Chart)	Expense Type			
4 00 00	Supplies			
4 25 00	"	- Linen		
4 25 10	"	"	- Patient Wearing Apparel	
4 25 20	"	"	- Staff Wearing Apparel	
4 60 00	"	- Medical & Surgical Supplies (< $250)		
4 60 50	"	"	- Sutures & Staples	
4 60 52	"	"	"	- Staples

16 Although not explicitly reviewed, financial secondary codes are also used to capture revenues, assets, liabilities and equity transactions.

By combining a secondary code (describing the nature of the expense) with a primary code (describing the responsible functional centre), it is possible to build a comprehensive general ledger structure. For example, gowns purchased for use in the cardiac operating room would be coded as 2-60-40/4-25-10.

The Patient Flow Model assigns financial secondary codes to Resource Nodes. This provides a numerical mapping between a specific Resource Node and an account in the hospital general ledger. In contrast to the coding scheme used by the MIS Guidelines, however, a primary code is not associated with Resource Nodes. The matching between primary and secondary codes occurs during the solution of the model and is decided by determining which activity (each of which has an associated primary code) made use of which Resources (each of which has an associated secondary code.)

In addition to being used to capture financial data, the secondary code block is also used to capture data regarding quantities of resources used, and levels of activity within a functional centre. The statistical chart of accounts consists of a hierarchical block code similar in structure, but different in meaning from that used in the secondary financial chart. Examples of statistical chart of account numbers appear below.

Secondary G/L Code (Statistical Chart)	**Statistic**			
4 00 00	Patient Activity			
4 18 00	"	- Non-scheduled Visits (# of)		
4 18 10	"	"	- Emergent (# of)	
4 18 20	"	"	- Urgent (# of)	
4 42 00	"	- Mothers Delivered (# of)		
4 42 2	"	"	- Forceps (# of)	
4 42 2 40	"	"	"	- In Labour Room (# of)
4 42 2 50	"	"	"	- In Delivery Room (# of)

Statistical codes drawn from the MIS Chart of Accounts can be assigned to any node in the Patient Flow Model for which there is a count or occurrence variable. (The occurrence variable is always denoted as *w*.) As with financial secondary codes, the matching between primary and secondary codes occurs during the solution of the model and is determined by examining which Treatment (each of which has an associated primary code) triggered the event denoted by the statistical chart code. For example, a count of the number of emergent, non-scheduled patients being taken to the cardiac operating theatre is captured using the code 2-60-25/4-18-10.[17]

The mapping of primary codes to Treatment Nodes, secondary financial codes to Resource Nodes, and secondary statistical codes to any node with an occurrence value, allows the Patient Flow Model to generate pro-forma statements that can be compared with the financial output obtained from a hospital's general ledger system. This facilitates the validation of output from the Patient Flow Model.

4.7 Cost Classification by the Patient Flow Model

Conventional approaches to costing traditionally group costs into one of two categories. Costs are considered to be either *direct* or *indirect*.

[17] It is impossible to tell by simply looking at the combined primary/secondary code whether the related data element is financial or statistical in nature. (Note how the financial secondary code 4-00-00 indicates Supplies, while the statistical secondary code 4-00-00 indicates Patient Activity.) In hospitals where a combined financial/statistical ledger is maintained, an alpha indicator is used in the first code block to indicate whether the secondary code is financial (F) or statistical (S).

Direct costs are costs for which a clear cause and effect relationship exists between the cost and a cost object. For example, the cost of a drug and the wages of the nurse required to administer the drug are easily seen to be the product of a patient requiring an injection. The cause (patient needs injection) and effect (hospital must pay for drug and nurse) is easy to identify, easy to measure, and easy to associate with the patient receiving treatment.

While some costs are easily identified with a specific patient, other costs are much more difficult to associate with a specific patient. This may be true even if it is obvious that the cost was incurred to support the treatment of patients in general. This is because the relationship between expenditures and the cost objects for which expenditures are incurred is not always evident. For example, most hospitals have a senior executive officer. This person is responsible for overseeing the management of the facility and for providing a link between the facility's governing body and its care providers. Without the leadership of the senior executive, the hospital will not function as efficiently. Because the senior executive is involved (albeit indirectly) in the provision of care, it is appropriate that some portion of the senior executive's salary be reflected in the cost of providing care to each patient. Determining the portion of the senior executive's salary that should be reflected in each patient is much more difficult.

Costs that are difficult to associate with a specific cost object because the cause and effect relationship is difficult to discern are called overhead or indirect costs. The challenge for any costing system is to develop a fair way to associate these costs with cost objects.

One of the reasons activity-based costing systems have been promoted as an attractive alternative to traditional two-stage costing systems is that activity-based costing systems provide a better mechanism for identifying cause and effect relationships between indirect cost pools and cost objects. Activities provide the link, and the assignment of costs occurs in proportion to the level of activity triggered by the cost object. The challenge remains, however, to ensure that activities which occur in greater frequency do not attract larger amounts of overhead simply because of the frequency with which the activity occurs. One of the ways to overcome this problem is to re-examine the way in which costs behave and are subsequently classified.

A five year study undertaken at Harvard University [Cooper and Kaplan, 1992] sought to develop a conceptual foundation for the design of cost systems that would address this problem. The classification system emerging from the study has important implications for the development of contemporary costing systems.

This study identified that classifying costs as being either direct or indirect does not fully explain the behaviour of many costs, and it was the way in which costs behave that must be understood in order to properly implement activity-based costing. This is because the drivers used to move costs from resources to activities and from activities to cost objects rely on an understanding of the behaviour of costs.

4.7.1 Recognizing Different Cost Behaviours

Rather than consider all costs to be either direct or indirect, the study proposed instead to classify costs based on the cost's behaviour. Four types of cost behaviour were noted:[18]

Treatment related costs	Costs that vary in direct proportion to the number of Treatments provided. These costs are incurred for activities that support specific patient interventions. An example is administering a drug.
Encounter related costs	Costs that are incurred only once, irrespective of the number of Treatments a patient receives. An example is the cost of admitting a patient.
Program sustaining costs	Costs that are incurred to support the availability of a program. The cost to perform a yearly accreditation of the laboratory is an example.
Facility sustaining costs	Costs that create the ability to care for all patients, such as heating and lighting, and general administration.

The Patient Flow Model allows users to employ Cooper & Kaplan's approach to cost classification. A cost driver is selected for each cost pool (Resource, Resource Package, or Treatment) that reflects the behaviour of costs in the cost pool. For example, encounter related costs are assigned to Treatments using encounter related drivers such as a one time charge for admission. Other cost assignment bases are shown in the following illustration.

[18] Terminology has been adapted for use in the Patient Flow Model. The four cost classifications proposed by Cooper and Kaplan [1991] were Unit Costs, Batch Costs, Product Costs and Facility Costs.

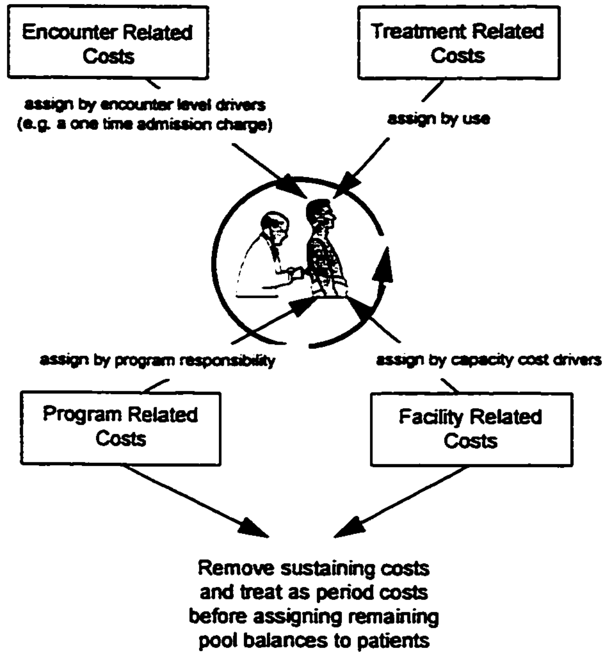

Figure 4.7A
Cost Classification in an Activity-Based System

Cooper and Kaplan's [1991] work also reinforced our understanding of the arbitrary nature of cost allocations that are made in the absence of causality. While causality can often be identified at the treatment and encounter-related levels, components of many program-related and facility-related costs are difficult to associate with specific patients, even when using activity-based costing. Because arbitrary allocations must be used to compensate for this difficulty, it is argued that costs of a sustaining nature be removed from the cost pools before the remaining costs are assigned via the activity-based costing process to patients. Removing sustaining costs from the allocation process reduces the magnitude of the arbitrary cost distributions.

Whether users subscribe to this premise is a matter of personal choice. The Patient Flow Model supports both a fully allocated view of costs and can also be adapted to allow sustaining costs to be identified and held as a line item at the Resource Node level.[19]

4.8 User Views

The concept of a *user view* is based on the premise that there is more than one way to view a common pool of data, and that each view of the data is in itself correct and complete. User views are an extension of the physical and logical schema[20] concepts developed in the information systems literature to support relational database design. Key to the concept of user views is that the information generated under each view is based on the same common repository of data, but the data elements *available* to the decision-maker and the *means* by which the data elements are arranged can differ considerably.

The departmental and global dimension of reporting used by Canadian hospitals are examples of *user views*. Each user view is prepared using a common pool of data structured around the MIS chart of accounts. Each user view is designed to meet the specific needs of different decision makers. And each user view uses different mechanisms to calculate cost and performance information. Choosing to examine indirect and full costs are also examples of using user views to selectively choose certain data elements from a larger data pool (the complete

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[19] Table 5.4M in the following chapter illustrates the application of this reporting structure.
[20] *Schema* is the term used to describe the definition of the format and relationship of data elements in a database structure.

financial/statistical reporting system), allowing cost reports to be tailored to meet specific user requirements.

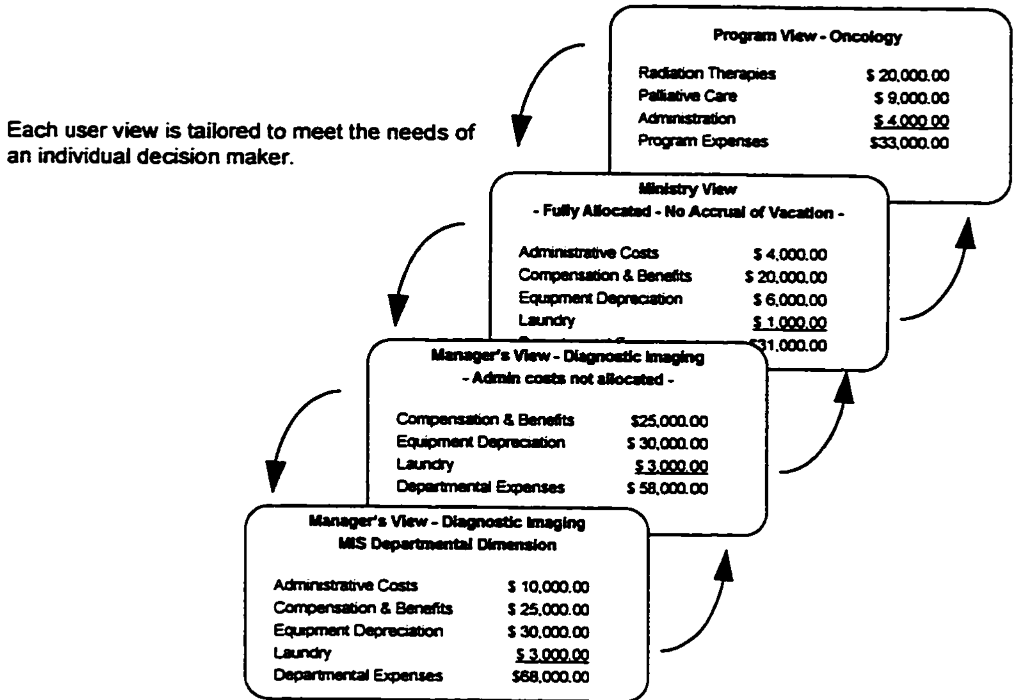

Figure 4.8A
Many Views of the Same Data

User views allow decision-makers to legitimize their local reporting requirements without compromising the reporting needs of other decision-makers. These other decision-makers might include provincial health ministries/departments, the federal government, regional health boards, and other users of information within the same facility. In a facility where all care is delivered using a program oriented model, user views can be used to create cost reports organized around programs. Simultaneously, when needed for other purposes, a user view organized around traditional functional centres can be created.

Extending the user view concept, it is possible to define a "provincial reporting" user view (e.g., a report that assumes vacation costs are accrued and capital assets are depreciated within each functional centre), a "Statistics Canada" user view (e.g., extracting selected performance indicators and financial balances), or a "Board of Trustees" user view (e.g., a summary of direct costs incurred in major functional centres, ignoring vacation accruals.) Once the rules and data required to produce each "view" is defined to the model, financial managers are freed of the tedium of producing special reports in response to individual requests. Most notably, the user view concept respects the over-riding principle of choosing local validity over comparability.

The Patient Flow Model fully supports the concept of user views. The Patient Flow Model does not enforce a specific presentation format for financial information. Users are free to apply accounting rules and costing conventions designed to ensure information generated by a Patient Flow Model is presented in a manner that specifically addresses the user's decision making requirements.

4.9 Summary

This chapter has explored a number of issues related to the Resource Dimension of the Patient Flow Model. The method by which the activity-based costing paradigm is incorporated into the structure of the Patient Flow Model has been demonstrated. Using an activity-driven approach to cost generation provides considerable flexibility to managers seeking to use output from the Patient Flow Model for decision making purposes.

The method by which MIS chart of account codes can be mapped to components of the Patient Flow Model was presented. The link between the chart of accounts and the Patient Flow Model is needed to allow hospitals to populate models and validate results.

And finally, it was shown how the Patient Flow Model incorporates contemporary ideas emerging in management accounting practice regarding the appropriate treatment of unused capacity costs, the classification of costs according to cost behaviour, and the treatment of sustaining costs.

Chapter 5
Implementing Patient Flow Models: Methodology & Findings

5.0 Overview

Chapter Three outlined the conceptual underpinnings of the Patient Flow Model and provided detailed information regarding the model's component parts. Chapter Four introduced the method used by the Patient Flow Model to track and record the consumption of resources and the cost of providing care. Chapters Three and Four dealt with the theory behind the model. This chapter advances the discussion by shifting the focus from the theoretical to the applied domain. The observations presented in this chapter stem from experience gained in the design and implementation of prototype Patient Flow Models. This chapter introduces;

- the methodology developed as part of this research for the development of Patient Flow Models including detailed objectives, tasks and checkpoints for each development step;
- rules to guide decisions related to the granularity when representing Treatments in Patient Flow Models networks;
- a critical discussion of the issues and challenges faced during each stage in the development process based on actual experience;

- presentation of the three prototype models (referred to as the vaccination, chest pain, and traumatic stress models) created as part of this research; and
- representative output and network specifications for a prototype model developed in an actual healthcare setting.

5.1 From Theory to Practice - Developing Patient Flow Models

This section introduces the methodology developed to create Patient Flow Models in real-world clinical environments. The development methodology is outlined briefly in Section 5.1.1. Section 5.1.2 reviews the methodology in detail, outlining the objectives for each step in the development process, the tasks that must be undertaken, checkpoints that must be achieved, and lessons learned as the development methodology emerged. Section 5.1.2 also serves as a detailed design document for users interested in developing Patient Flow Models in real-world settings.

5.1.1 Overview of the Patient Flow Model Development Methodology

Patient Flow Models are built using a four-stage development methodology fashioned after methodologies used for the creation of evolutionary prototypes [Earl, 1989]. The four stages in the development methodology can be broadly described as learn, design, build and test.

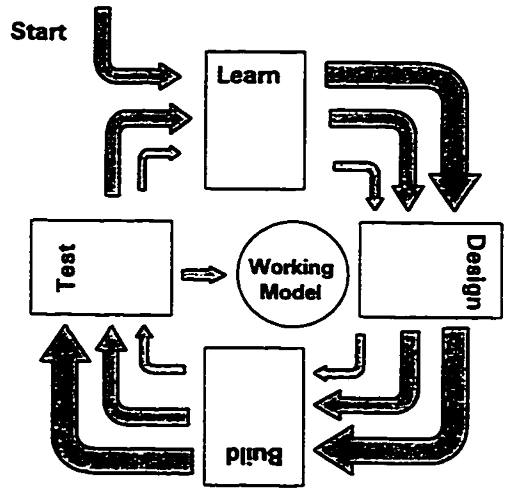

Figure 5.1A:
Prototyping the Development of Patient Flow Models

In the context of the Patient Flow Model, these stages can be more specifically described as:

1. Determine whether the health care domain is amenable to modelling (or on development cycles other than the first - address results of the test phase of the previous cycle.) *(learn)*

2. Gather the data necessary to define and draw a Patient Flow Model at the conceptual level. *(design)*

3. Implement the model using the computerized tool of choice. *(build)*

4. Ensure that the resulting model correctly reflects the problem domain. *(test)*

This four stage cycle must be repeated at least twice. The ***design*** and ***build*** phases of the first cycle focus on the collection and modelling of data related to patient flows (i.e., the clinical dimension.) A subsequent cycle concentrates on the collection and modelling of data related to cost flows (i.e., the resource dimension.) What emerges at the end of a series of repetitive cycles through the *learn, design, build* and *test* stages is an evolutionary prototype that can be put to use as a decision-support aid in healthcare settings.

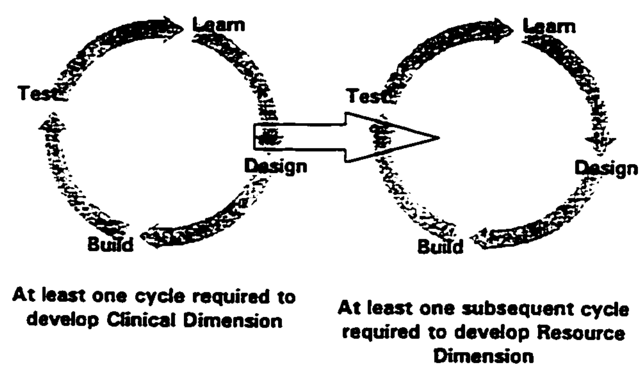

Figure 5.1B:
At Least Two Development Cycles are Required

Table 5.1A summarises the major steps followed to develop the working Patient Flow Models discussed in this research. Section 5.1.2 extends the discussion of the development methodology by exploring in detail the tasks that must be undertaken during each step. This discussion is based on experience gained in the development of the prototypes created as part of this research.

Table 5.1A		
The Patient Flow Model Development Methodology		
Step	Description	Relative Complexity
1	Determine suitability of problem domain	Low
2	a) Gather clinical data and develop a corresponding Patient Flow Model. b) Represent Clinical Dimension data using computerized tool of choice.	Low or High (depends on strategy chosen)
3	a) Gather resource data and develop a corresponding Patient Flow Model. b) Represent Resource Dimension data using computerized tool of choice.	Medium to High (depends on availability and format of accounting data)
4	Populate & validate the computerized model	Medium
5	Use computerized model as a decision support aid	Low

5.1.2 The Prototype Setting

The research reported in this chapter is based upon the experience gained gathering data to create evolutionary prototypes of the Patient Flow Model in a live healthcare setting. These prototypes represent the third series of models developed for this research. The two earlier demonstration models (the vaccination and chest pain series) shaped thoughts about the development methodology that should be used for a live implementation. The result was the five stage methodology presented in Table 5.1A.

Section 5.1.3 applies this methodology in a live setting. The *Objective* and *Tasks/Data Collection* headings reflect knowledge that formed a part of the planning stage for this process. The sub-sections titled *Consequences/Implications* and *Lessons Learned* report the findings of this process and indicate (where required) modifications to the methodology that need to be incorporated prior to creating a subsequent set of prototypes.

The live setting used to gather data for a demonstration prototype of the Patient Flow Model is a large accredited psychiatric hospital with over 1500 admissions per year. Details of the setting, and an explanation of the suitability of this setting for modelling are presented in Section 5.4.1 on page 187. Prior to selecting this hospital as a site from which to gather data, an attempt was made to use the orthopaedic surgical program at a mid-sized community hospital. As Section 5.1.3 discusses, while the orthopaedic program was amenable to modelling using the Patient Flow Model, the strong correlation between the choice of "most responsible physician[1]" and the treatment plan followed by patients meant there was little opportunity to explore the optimisation capabilities of the Patient Flow Model. (Models in the orthopaedic setting would have been completely descriptive.) A setting in which there was more choice in treatment protocols followed by patients was sought, and the psychiatric hospital was identified as an interested participant. Buy-in to the project was secured from the senior executive team and from the clinical providers working in the units to be studied. Ethics approval for the project was obtained from the hospital's Medical Advisory Council. Throughout the project, excellent support was received from both the executive and the clinical providers. Numerous meetings were held at the hospital site and clinical providers provided feedback on the developing Patient Flow Models. The resulting clinical and resource dimension models are presented in Sections 5.4.2 and 5.4.3 respectively.

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[1] Hospitals usually assign one physician to act as the person primarily responsible for the patient's care. In this situation, the most responsible physician was usually an orthopaedic surgeon.

5.1.3 Specifying and Creating Patient Flow Models

This section provides a detailed explanation of the issues that must be examined during each step in the development of a Patient Flow Model. In doing so, this section forms a detailed design document for users interested in developing Patient Flow Models. The discussion presented in this section is based on experience gained during the creation of the demonstration prototypes developed during this research.

The objective for each step in the development process is provided, together with tasks that must be completed and checkpoints that must be passed. Lessons learned during the iterative development of the prototypes created as part of this research are presented where relevant.

Step 1: Determine Suitability of the Modelling Environment (Learn)
(Relative Complexity: Low)

Objective (Step 1)

To determine whether the problem domain of interest is amenable to modelling using the Patient Flow Model.

Tasks/Data Collection (Step 1)

A number of factors influence how amenable a healthcare setting is to being modelled using the Patient Flow Model. Some of these factors are intrinsic to the model itself (such as the assumption of linearity), while other factors were discovered as a result of the experience gained developing models in various settings.[2] During this first step in the model design process, the modeller must ascertain whether factors conducive to the implementation of Patient Flow Models are present. The tasks required to accomplish this are described below.

Step 1/Task #1: Ensure the program to be modelled can be clearly defined.

Issue:

There must be agreement regarding the scope of the treatment program chosen for modelling, and the stakeholders must have a clear understanding of what is within the model domain and what will be left outside the model domain.

Illustration/Example:

If it is decided to model a hospital's surgical program, there must be consensus about what procedures are part of the surgical program.

e.g., Does the program include only procedures performed in the regular operating theatres, or does it also include caesarean sections performed in the obstetrical unit? Are only in-patient procedures to be modelled (as only they draw on hotelling resources of the hospital) or will out-patient procedures be included as well?

Consequences/Implications:

Failure to clearly specify the boundaries of the problem domain will result in models that are poorly defined and difficult to operationalise. Data collection is also severely compromised.

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[2] A variety of settings were explored as part of this research. These included an orthopaedic surgical program, an emergency department, an eating-disorders program and a traumatic stress program.

Step 1/Task #2: Ensure that most patients who enter the program being modelled are expected to complete the program.

Issues:

1. The Patient Flow Model assumes that the underlying goal of the healthcare facility is to move a patient from a state of poor health to a state of better health.

2. The Patient Flow Model has only been exercised in environments where it is expected all patients entering a treatment program will ultimately be separated from the program.

Illustration/Example:

Surgical programs, medical programs, and other strongly interventionist treatment programs are excellent candidates for modelling using the Patient Flow Model. A characteristic of programs of this type is that there are easily identifiable Clinical Paths between the point of admission and the point of separation.

The Patient Flow Model has also been exercised in settings with more complex clinical paths. These are clinical paths through which a patient may cycle a few times before being separated. A psychiatric hospital is a setting where less straight-forward clinical paths are found. Note, however, that even in this setting, most treatment programs result in patients being separated.

Consequences/Implications:

The behaviour of the Patient Flow Model is well understood in the acute healthcare settings for which the model was developed. The behaviour of the model has *not* been explored in non-acute settings where the assumption that most patients entering the treatment program will be separated from the program does not hold. A long term care facility which admits patients and then cares for these patients over extended periods of time is an example of such an environment. Care should therefore be exercised when applying the Patient Flow Model in these settings.[3]

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[3] One of the difficulties expected to be encountered in such a setting is that the duration of individual Treatments may be longer than the model's planning period. Work-arounds to accommodate this requirement can be developed, however, the testing of these work-arounds was not within the scope of this project.

Step 1/Task #3: Determine whether generally accepted clinical protocols exist for all conditions in which patients can present.

Issues:

Determining the sequence of Treatments patients will receive given the State in which they present requires significant medical training. It is expected that many model designers will lack this training, requiring that alternate methods to gather this information be sought.

The preferred method is to make use of generally accepted treatment protocols. Treatment protocols represent 'best practices' and provide an ideal means to define acceptable clinical paths through a Patient Flow Model network.

In the absence of treatment protocols, it is necessary for the model designer to reconstruct the sequence of treatments received by patients using medical records.

Illustration/Example:

Commercialised methods to define treatment protocols (such as Care Plans® and Care Maps®) are used by many hospitals. Reference should be made to these tools when developing Patient Flow Models. Treatment protocols exist for most high risk, highly interventionist diagnoses such as myocardial infarction.[4]

Consequences/Implications:

Using generally accepted treatment protocols has two benefits. The first is that using treatment protocols ensures that the model captures all of the elements of appropriate medical care for a given condition.

The second important consequence of making use of generally accepted treatment protocols is that this eliminates the need to "pull" and interpret the medical charts of sample patients.

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[4] Heart attack.

Step 1/Task #4: Determine whether the domain being modelled makes use of captive resources.

Issue:

One of the notable strengths of the Patient Flow Model is the model's ability to allow multiple Treatments to compete for the use of shared Resources. The model assumes, however, that Resources modelled within a Patient Flow Model are only used by Treatments in the same Patient Flow Model. In situations where this is not true, work-arounds must be implemented.

Illustration/Example:

Assume a Patient Flow Model is to be developed for a surgical cardiac program that has its own dedicated pool of nurses. The ability of the Emergency Department to borrow some of these nurses because of an unusually heavy Emergency caseload makes it more difficult to model the cardiac program. This is because the demands placed on the surgical nurse Resource by the Emergency Department cannot be dynamically determined by the Patient Flow Model.

Consequences/Implications:

Treatment programs with captive resources are the most suitable for modelling. While work-arounds can be implemented to account for Resource demands coming from outside the area being modelled[5], the greater these Resource demands, the more the results generated by the Patient Flow Model may be compromised because of the assumptions about these demands that must be built into the model.

Step 1/Task #5: Determine whether the healthcare facility has a comprehensive resource tracking system.

Issue:

A tremendous amount of data must be gathered regarding Resource availability, cost and usage in order to implement a Patient Flow Model.

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5 See Section 6.3.3 for ideas.

Consequences/Implications:

Hospitals with Global Dimension costing capabilities already have comprehensive financial, statistical and workload measurement tracking systems in place. Accessing data in these systems saves considerable legwork for the model designer.

By extension, Patient Flow Models are more easily implemented in environments that have already developed activity-based costing systems. In the absence of an activity-based costing system, the ground-work to implement activity-based costing must be laid before a Patient Flow Model can be operationalised.

Step 1/Task #7: Consider whether the assumption of linearity is reasonable.

Issues:

The Patient Flow Model employs linear programming routines to generate solutions. All inputs (and outputs) from nodes in the model are assumed to consist of linear combinations of possible inputs (or outputs).

In addition, integer constraints on decision variables were omitted in the prototype models.[6]

Illustration/Example:

The linearity assumption requires that if *n* patients receive a Treatment, the use of Resources by this group must be equal to *n* times the Resources that would have been used had only one patient received the Treatment.

Not implementing integer constraints on patient flows means that it is not uncommon for a Patient Flow Model to identify that 7.34 nurses will be needed to care for 45.6 surgical patients. It is obviously impossible to care for only 0.6 patients, likewise, it is recognised that hiring 34/100ths of a nurse is not possible.

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6 The model can be modified to use mixed-integer routines. (Integer routines for patient flows along Clinical Pathways and linear routines for resource flows.)

Consequences/Implications:

The Patient Flow Model should not be used in situations where the consumption of resources is a non-linear function of the number of patients treated. In such a case a software package (such as MINOS) capable of handling non-linear expressions would need to be used.

A simple extension to the Patient Flow Model is introduced in Chapter 6 that demonstrates how problems of a non-linear nature can be addressed by making small changes in the design of the Treatment Node.

The presence of non-integers in a planning tool such as the Patient Flow Model is not a significant issue. In a scheduling model, integer values are more significant.

Milestones/Checkpoints (Step 1)

Table 5.1B summarises the factors that must be considered in order to determine the suitability of the problem domain for modelling using the Patient Flow Model. Each factor is presented in the form of a question, together with the preferred finding.

Lessons Learned (Step 1)

The key lesson learned during this stage was the need to develop the environmental checklist presented in Table 5.1B. The most problematic environmental factor was finding programs that made use of relatively captive resources. As can be expected, there is considerable resource sharing among hospital programs. Identifying programs where captive resources existed required care in selecting candidate programs for study. One promising candidate program that was ideal in all other respects was rejected from the study because it failed to pass this test.

Table 5.1B	
Summary of Questions to Ask to Determine Suitability of the Modelling Environment	
Question	Description
1	Is the treatment program to be modelled one that can be clearly defined? ***Checkpoint:*** Answer should be 'yes'.
2	Are most patients who enter the treatment program being modelled expected to complete the treatment program? ***Checkpoint:*** Answer should be 'yes'.
3	Do generally accepted treatment protocols exist for all conditions in which patients can present? ***Checkpoint:*** Answer should be 'yes'.
4	Does the area being modelled make use of captive resources? ***Checkpoint:*** "Yes" is the preferred finding. Non-captive Resources can be accommodated, but this will require the use of work-arounds.
5	Does the hospital have a comprehensive resource tracking system? ***Checkpoint:*** "Yes" is the preferred finding. Extensive, manual data collection will be required otherwise.
6	Is the assumption of linearity reasonable? ***Checkpoint:*** "Yes" is the preferred finding. Non-linear solution engines must be employed if the finding is "no."

It was originally thought that the problem of captive resources would disappear if a total hospital was modelled. Examination showed, however, that even exerting the effort required to model a complete hospital would not eliminate the problem. This is because hospitals are increasingly sharing the cost and use of expensive equipment housed in one facility but accessed by both. MRI scanners, nuclear medicine facilities, and specialised lab testing equipment are examples of resources that are often shared between facilities.

Step 2: Collect & Model Clinical Dimension Data (Design, Build, Test, Learn)

Relative Complexity: Medium to High (depends on collection strategy chosen)

Objectives (Step 2)

1. To gather the data necessary to build the Clinical Dimension of the model and to represent this data using a Patient Flow Model diagram. (Design)

2. To convey Clinical Dimension data to the computerized solution tool of choice. (Build)

3. To validate the resulting clinical flows with medical practitioners. (Learn)

Tasks/Data Collection (Step 2)

Two data collection tasks are required. The first is to identify the various Treatments and Patient States that exist within the program being modelled. The second is to establish the Clinical Pathways connecting Treatments and Patient States, and where applicable, the distribution factors associated with these connections.

Considerable judgement must be exercised by the model designer during this step in the development methodology. This is because a number of decisions must be made with respect to the level of aggregation that should be used to model the treatment protocols found in the program being modelled.

Step 2/Task #1: Identify Treatments and Patient States

The model designer has two choices with respect to identifying Treatment and Patient States.

Choice 1 - Exploit the availability of generally accepted treatment protocols.

Generally accepted treatment protocols can be used to extract information on the accepted Clinical Pathways within the program being modelled.

This method was used with considerable success for one of the larger prototypes built as a part of this study, and is deemed to be the preferred option for identifying treatments and patient states.

Choice 2 – If treatment protocols do not exist, this information must be obtained by extracting details of chartable interventions from the medical records of patients who have previously been treated by the program being modelled.

This is a tedious process, and requires access to both the medical records of past patients, and a medical records technician able to interpret data contained in the medical charts.

This process was used for an early Patient Flow Model prototype and was found to be inferior to the process of using generally accepted treatment protocols.[7] This is because model designers can expect to find considerable variation in treatment practices among physicians (even when dealing with the same diagnosis) making it particularly difficult to determine the path(s) most patients could be expected to take through a series of Treatments given their presenting condition.

Step 2/Task #2: Determine paths between Treatments and Patient States

As with the process of identifying the Treatments and Patients States themselves, two approaches can also be used to gather the data needed to define the linkages between Treatments and Patient States. In most cases, the data being sought are values for Treatment Distribution Factors. Depending on the modelling environment, there may also be a need to determine values for Treatment Acquisition Factors and Patient State Distribution Factors.

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[7] In addition to the logistical challenges faced by having to extract Clinical Pathway information from medical charts, the real complication is that it can be very difficult to determine what is the normal treatment protocol for a particular diagnosis as each medical history reflects the treatment plan adopted by individual medical practitioners. Physicians were found to differ in their management of patients in environments where standardised treatment protocols did not exist.

The two approaches are:

Approach 1 – Extract the required information from the patients' medical records.

Using a representative sample of patients, it is possible to retrospectively determine the proportion of patients proceeding to each possible outcome State for any given Treatment.

This approach has all the advantages and limitations noted earlier for using medical records to identify Treatments and Patient States.

Approach 2 – Gather data in a prospective mode by following the flow of patients through the treatment process.

Have patients keep a diary in which they record Treatments received and the order in which they received the Treatments. By compiling the data contained in these diaries it is possible to develop a profile of Treatment Distribution Factors. This approach works well in psychiatric settings or other environs where patients are self-supporting.

Step 2/Task #3: Determine the appropriate granularity to use for the presentation of Treatments.

Once data on the various Treatments and Patient States that exist within the model environment is gathered, the model designer must decide on the level of granularity that should be used to represent these elements within a Patient Flow Model. In an earlier chapter it is shown that three conditions must normally be met in order to model an activity as a Treatment. These conditions are:

1. Patients must be involved as inputs or outputs of the Treatment.
2. Some proportion of the input patients must undergo a change of state.
3. The Treatment must be an activity that is normally recorded in the patient's medical record. (These are called "chartable" Treatments.)

While these conditions provide an excellent starting point for designers charged with developing Patient Flow Model based information systems, the third condition can be relaxed when needed to better match the Patient Flow Model with local decision-making requirements.

Treatments normally modelled individually (such as a series of chartable events) can be grouped to create a single "macro" Treatment when the underlying Treatments are not relevant to the decision-maker's needs. For example, the series of Treatments required to collect a blood donation can also be modelled as a single Treatment, DONATE BLOOD. The process of grouping multiple Treatments into a single "macro" Treatment is called *compression,* while unbundling a Treatment into a series of more refined Treatments is called *expansion.* Compression and expansion are horizontal abstractions in the Patient Flow Model.

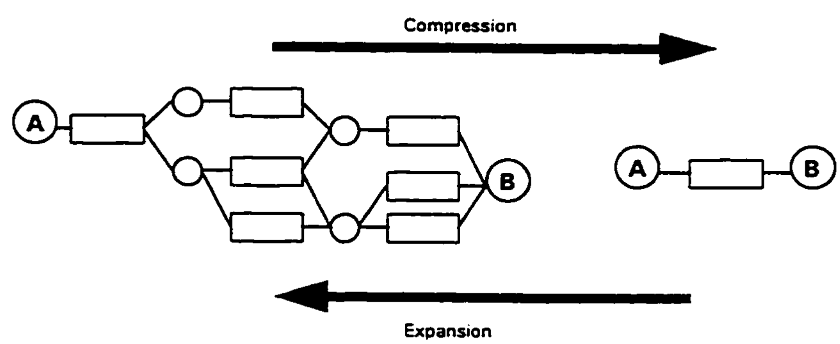

Figure 5.1C:
Compressing and Expanding Treatment Nodes

A decision rule is required to determine whether a series of Treatments can be modelled as a single Treatment. The rule is that Treatments eligible for compression must share common initial Patient States and one or more common terminal Patient States. In Figure 5.1C, Patient

State 'A' is a common initial state to the seven Treatments in the Patient Flow Model diagram, and irrespective of the treatment path followed by a patient, the patient always emerges in terminal state 'B'. Because the seven Treatments between 'A' and 'B' share a common initial and terminal Patient States, the seven Treatments can be recast as a single Treatment.

Other compressions are possible. For example, the Treatments indicated by ① and ② in Figure 5.1D can be compressed to create two higher level Treatments. The condition of common initial and terminal nodes is met in both cases.[8]

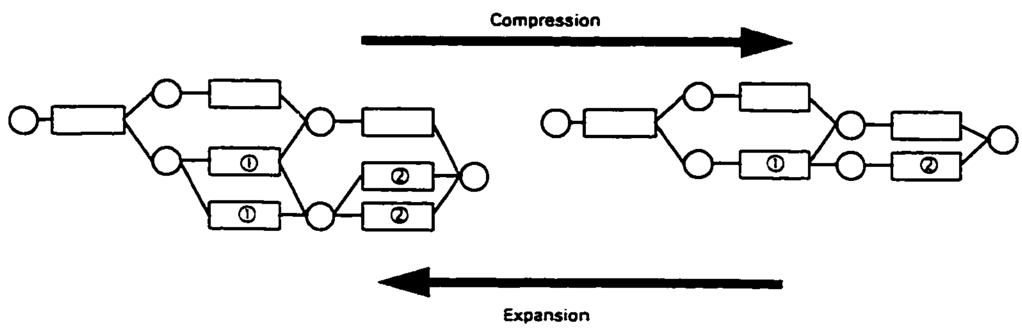

Figure 5.1D:
Compressing and Expanding Treatment Nodes

Model design decisions to compress or expand Treatments are made in order to accommodate the decision-making needs of the model user. Because of the significant information loss that can result from compression, it is recommended that in the absence of over-riding decision-making needs on the part of the model user, chartable events should be used to

[8] Note that although these Treatments can be compressed, doing so will require determining revised values for the Treatment Distribution Factors.

define Treatments. Compression and expansion are tasks managed by the model designer. It is not possible for the model user to dynamically compress or expand Treatments.

Step 2/Task #4: Represent Clinical Dimension data using the computerized solution tool of choice.

Choose a computerized application package that has:

- data storage capabilities;
- data reporting capabilities; and,
- data manipulation functionality (including mathematical programming routines).

Application packages well suited to supporting the implementation of Patient Flow Models include:

- full-featured spreadsheets with built-in linear programming routines (e.g., Microsoft Excel, Lotus 1-2-3)
- database engines (e.g., Microsoft Access)
- dedicated linear programming languages (e.g., LINDO)
- add-in tools (e.g., What's Best)

Milestones/Checkpoints (Step 2)

The completed Patient Flow Model diagram must be verified by potential model users and staff members who work in the area being modelled. Questions to ask of healthcare workers familiar with the environment being modelled include the following:

Question 1 - Does the treatment protocol you use for each presenting Patient State exist in the diagram? (i.e., Can the medical practitioners trace a Clinical Path that matches the way in which they treat a patient?)

Question 2 - Do the Patient State Nodes accurately reflect the condition(s) in which patients can emerge from Treatment?

Question 3 - In what Patient States can patients be admitted to the program being modelled? In what Patient States is it not possible to admit patients?

Question 4 - In what Patient States can patients be separated from the program being modelled? In what Patient States is it not possible to separate patients?

Lessons Learned (Step 2)

Although model users have considerable flexibility with respect to how Treatment nodes are reflected within the Patient Flow Model, it was found to be advantageous to use chartable events as the distinguishing criteria to define Treatments. Doing so provides a direct link between medically accepted treatment protocols and the Patient Flow Model. This establishes a bridge between the domain of the medical practitioner and the domain of the model user. Two factors contribute to the strength of this bridge:

1. Medical professionals are trained to "think" in terms of treatment protocols. They are therefore already comfortable with this paradigm.
2. Protocols are only promulgated after consensus is reached among medical practitioners on the appropriate treatment plan for a patient having a given diagnosis. This ensures that treatment paths followed by patients in the Patient Flow Model have been previously confirmed by authoritative sources as acceptable. This frees the designer from needing to accommodate the wide variety of treatment plans that may exist for a given diagnosis.

Using chartable events to define Treatments also provides a method to distinguish between medical interventions (e.g., administering an injection) and supporting activities (e.g., preparing the serum.) In the absence of a guideline to distinguish between medical interventions (i.e., Treatments) and supporting activities (i.e., the assembly of Resource Packages), model users can become confused when deciding how to best classify and model an activity.

Another significant lesson learned during the development of the Patient Flow Model methodology dealt with the preferred method of determining Clinical Pathways. Because of the desire to model "real-world" events, it was originally decided that Clinical Pathway information was best gathered by examining the medical charts of recent patients in the program being modelled. This would ensure that the Clinical Pathways incorporated into the Patient Flow Model reflected actual practice. It would also permit Treatment Distribution factors to be calculated with some certainty.

It was discovered that the highly technical nature of the medical chart necessitated the use of hospital Records staff to identify patients, pull charts, and extract data. The process was slow and costly. Only early models were built using this process. Later models were constructed based on generally accepted treatment protocols.

A third lesson learned was that although medical practitioners quickly grasp the conventions used in the Patient Flow Model diagram, Patient Flow Model diagrams that focus on a single diagnosis are easier for practitioners to validate than Patient Flow Model diagrams encompassing multiple diagnoses. To overcome this problem, the model designer can create single diagnosis Patient Flow Model diagrams which are individually validated. The single diagnosis Patient Flow Model diagrams can then be combined by the designer to create a master Patient Flow Model.

Step 3: Gather Resource Dimension Data (Design, Build, Test, Learn)

Relative Complexity: Medium to High (depends on availability and format of accounting records)

Objectives (Step 3)

1. To gather the data necessary to develop the structure of the Resource Network.
2. To represent Resource Dimension data using the computerized tool of choice.

Tasks/Data Collection (Step 3)

The following data is required to develop the Resource Network in a Patient Flow Model. Suggestions regarding appropriate sources for each data element are also provided.

- For each Resource, collect information on cost, availability, acquisition quantity and minimum holding levels.
- Identify intermediate Activities that best explain the use of Resources by Treatments.
- Determine the cardinality of each relationship in the Resource Network.

Step 3/Task #1: Collect Information on Cost, Availability, Acquisition Quantity and Holding Levels for each Resource.

This information can usually be obtained from the hospital's accounting or finance department. Depending on the accounting information system in use, the task is either one of low complexity or one that is fraught with difficulties. In some settings, extensive use of the materiel management system will also be required. An effective strategy is to ask to see a copy of the program budget. Many line items represent Resources that should be reflected in the Patient Flow Model.

Many hospitals do not have fixed asset management systems in place. This makes it difficult to determine cost information for much of the supporting equipment used in the environment being modelled. Reasonable estimates can be used where required. Allow the model users to provide the estimates.

Step 3/Task #2: Identify intermediate non-Treatment activities that help explain the use of Resources by Treatments

For every resource driver identified, there is likely to be a corresponding Resource Package. Use the identification of intermediate non-Treatment Activities to guide the degree to which Resource Packages should be incorporated into the model.

If the hospital has an activity-based costing system, it is recommended that a Resource Package be created for every activity that is not already modelled as a Treatment.

Step 3/Task #3: Determine the cardinality of each relationship in the Resource Network.

In order to create a Patient Flow Model, it is necessary to determine the nature of the relationship between parent and child nodes in the Resource Network.

Of interest to the model designer is, "*how many units of the child node are required for* each *occurrence of the parent node?*" These values are Equivalency Multiplier parameters in the model.

Step 3/Task #4: Identify Resources that are also used by Treatments outside the domain being modelled.

If the environment being modelled has been defined carefully, a minimal number of Resources will be shared with other programs. (Notwithstanding this, reflecting a shared Resource in a Patient Flow Model can be accommodated if required.)

The challenge faced by the model designer comes when operationalising the model. In order to ensure that enough of a Resource remains available for Treatments that are not part of the model environment (but which use the Resource), the availability of the shared Resource either has to be artificially adjusted to reserve some portion of the Resource for Treatments not explicitly modelled, *or* a dummy Treatment must be introduced within the program being modelled to create an artificial demand for the Resource. See Section 6.3.3 for a discussion of this issue.

Step 3/Task #5: Represent Resource Dimension data using the computerized solution tool of choice.

Add the Resource Dimension data to the computerized model developed during Step 2.

Milestones/Checkpoints (Step 3)

The completed Patient Flow Model diagram should be shown to financial services staff so that they can provide input on the overall reasonability of the network structure created.

Lessons Learned (Step 3)

Care must be taken during this step in the development methodology to ensure that all material[9] Resources have been identified. If medical records are the source of data used to develop the clinical dimension of the model, an opportunistic strategy is to simultaneously extract information from the medical chart regarding Resource consumption of drugs, prostheses, and other patient specific supplies.

An alternative data gathering strategy is to examine secondary account codes[10] that have been used for all functional centres involved in the environment being modelled. Each secondary account code in use represents a potential Resource that must be reflected in the Patient Flow Model.

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[9] Material in a financial sense, i.e., significant.

[10] Secondary codes specify expense categories within an MIS Guideline compliant chart of accounts as used by Canadian hospitals.

The development of the Resource Network is assisted greatly if the model users have previously engaged in an activity-driven costing exercise. This is because thought will already have been given to determining the appropriate non-Treatment activities. In settings where activity-based costing initiatives had not previously been undertaken, considerable effort is required to determine the nature and structure of the Resource Network.

Because of the physical size of Patient Flow Model diagrams, care must be taken in their design to ensure linkages are properly reflected. Diagrams created for this study were prepared manually using a presentation package (Powerpoint). Presentation packages were found to be lacking many features that would assist in managing the diagramming task. The experience demonstrated that more suitable diagramming tools (such as VISIO or Corel Flow) that include diagram layering should be used for future development efforts.

Models developed in this study were implemented using Excel 4.0, and later using Excel 5.0. The flexible and familiar nature of the interface, and the ability to combine data storage, data manipulation and data reporting within one package were considered to be powerful arguments in support of using a spreadsheet interface to implement Patient Flow Models.

As models grew in size (as measured by the number of constraints and variables present in the model), it became apparent, however, that while spreadsheets offer a useful interface, they are unable to deal with the size and scope of the solution space that must be explored. In an attempt to overcome this limitation, *What's Best* was used in place of Excel's *Solver* engine for some prototypes. Limitations in the solution engine's ability to handle the number of constraints found in Patient Flow Models of even moderate complexity still emerged.

While Excel provided an excellent platform upon which to explore prototypes of the Patient Flow Model, the experience demonstrated that a more robust computerisation strategy is needed. It is recommended that future models be built using a database tool for data storage and reporting. Import/export routines should be used to move the data out to a mathematical programming tool where a satisfactory solution can be identified. The solution data can then be passed back to the database engine for presentation to the user.

Step 4: Populate & Validate the Computerized Model (Test)

(Relative Complexity: Medium)

Objective (Step 4)

To confirm the validity of the newly developed Patient Flow Model by populating the model with historical data and comparing model output with known historical results.

Tasks/Data Collection (Step 4)

The following steps are followed to validate a Patient Flow Model.

Step 4/Task #1: Select a recent historical period for which patient volume and cost information is available.

Obtain values for all parameters in the model. (If medical charts were used to extract clinical dimension data, use the period over which patients represented by the charts were in the hospital. If diaries were used to establish Treatment Distribution Factors, use the period over which the diaries were kept.)

Step 4/Task #2: Create an objective function that will create a discharge & patient holding profile equal to the actual profile of patients discharged & held during the period used to validate the model.

Step 4/Task #3: Populate the model with data representing the actual profile of patients either admitted or already in holding at the beginning of the model period.

Milestone/Checkpoint (Step 4)

In the context of the Patient Flow Model, validation testing involves gaining an acceptable level of assurance that the output from a descriptively-based Patient Flow Model matches the output from the hospital information system used to record expenses over the same historical period.

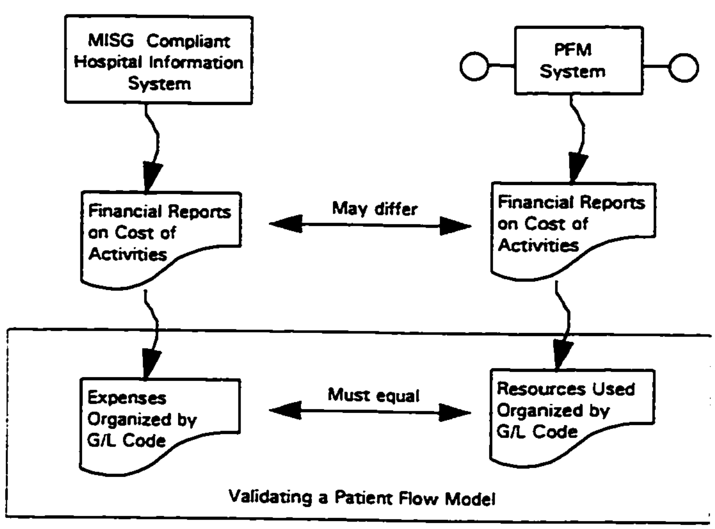

Figure 5.1E
Validating the Output from PFM Based Information Systems

For example, although the output from a Patient Flow Model and an MIS compliant hospital information system may vary with respect to the cost of activities performed, there can be no difference with respect to the number of patients treated (this is known based on real-world events) or the cost and quantity of resources actually consumed to provide treatment (which is also known based on real-world events.) Once a Patient Flow Model has been validated using descriptive data, the model can be used for prescriptive purposes.

5.2 Summary of the Development Methodology

Developing a Patient Flow Model is an iterative process as the designer cycles through the *learn, design, build,* and *test* phases. The methodology developed to support this research is based on the premise that it is beneficial to design and build the Clinical Dimension of a Patient Flow Model before adding Resource level data. Implementation can occur using any computerized solution engine with the requisite functionality. (See page 172.)

The development methodology presented in this section emerged itself through a prototyping process. Initial Patient Flow Models were built using a fifteen-step process which was later recast as the four stage methodology presented here.

With the groundwork laid for the process by which Patient Flow Models are developed, this chapter moves forward by presenting information on the prototype models that were built as a part of this study.

5.3 Initial Prototypes

Two prototype models were used to explore the design and structure of the Patient Flow Model. Lessons learned during the creation of these prototypes led to the development of the design methodology discussed in Section 5.1 and to the refinement of the structure of the Patient Flow Model from that first proposed.

5.3.1 The Vaccination Treatment

Patient Flow Model examples developed in previous chapters are based on actual treatment protocols, however, the examples were tailored to favour the presentation of specific features and characteristics of the Patient Flow Model. A simple, two-treatment model based on administering a tetanus vaccination served as the foundation to introduce the component parts of the Patient Flow Model. Although the vaccination model has only two treatments, multiple outcome states exist and the solution of the model requires that decisions be made regarding resource usage based on availability and cost.

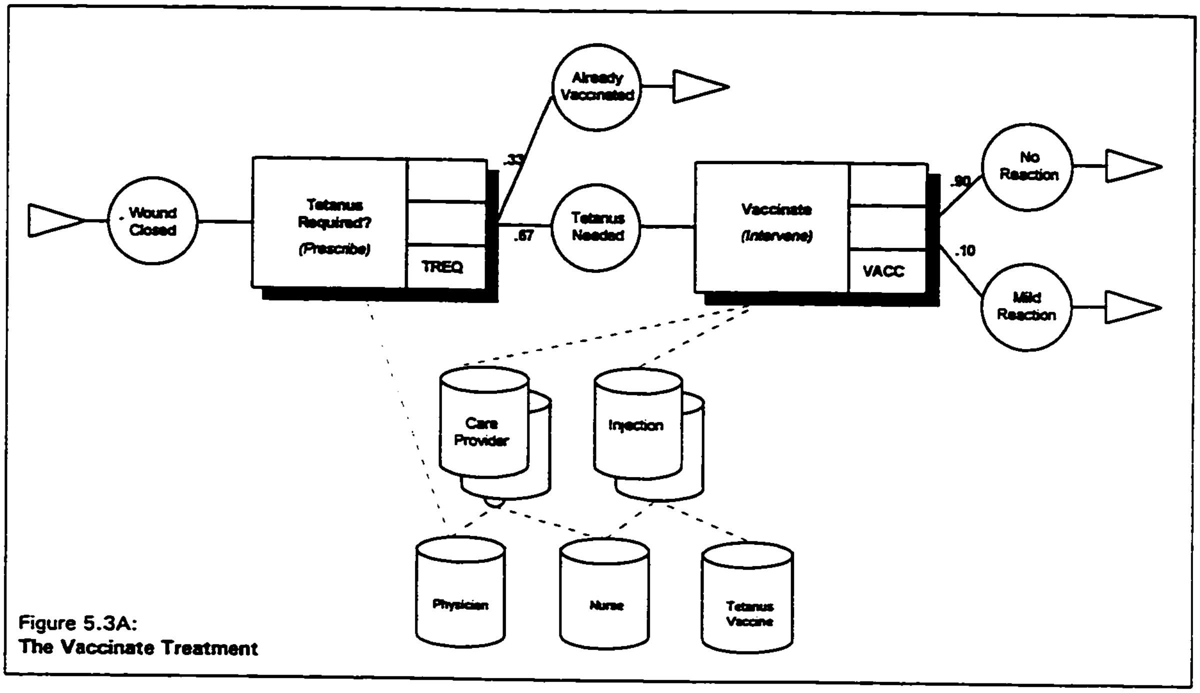

Figure 5.3A:
The Vaccinate Treatment

The vaccination example provided not only a base upon which the discussion in Chapter 3 could be developed, but was also used to explore the process by which the Patient Flow Model moves from being a conceptual model to a live, computer-implemented decision tool. The tetanus example, with its two Treatments and five patient States provided the foundation for the first prototype built to operationalise the Patient Flow Model.

The vaccination example was implemented using Microsoft Excel 4.0 for data capture and output presentation. The Excel Solver was used to operationalise the model. Despite the simplicity of the vaccination procedure, twenty-three computerized versions of the tetanus example were developed as evolutionary prototypes. Each successive revision of the model reflected a lesson learned about the best way to capture, manipulate, and present data.

While the ultimate aim of these evolutionary revisions was to optimise performance of the solution engine, many of the revisions in early prototypes were made not so much to optimise performance, but rather to minimise the crippling effect that particular approaches to data input and model definition had on search strategies used by the Excel Solver.

For example, early prototypes demonstrated that search times and solution success could be enhanced by substituting implicit boundary constraints for the more liberal explicit constraints which are a part of the model design. (An example of an implicit constraint is recognising that the number of patients who can follow a separation pathway can never exceed the total number of patients in the hospital.)

5.3.2 The Chest Pain Treatment

Lessons learned from the development of the tetanus vaccination prototypes were used to guide the development of a second series of Patient Flow Models. These were known as the chest pain models and dealt with a simple chest pain treatment protocol.[11] Whereas the tetanus example involved a single Treatment with multiple outcome states, the chest pain models introduce the complexity of multiple clinical pathways. The chest pain example is used in Chapter 4 to illustrate the mechanics of the cost accounting process employed by the Patient

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[11] Angina is a transitory clinical syndrome usually associated with symptoms that are thought to be indicative of coronary artery disease (such as severe chest pain).

Flow Model. Multiple resources exist in the chest pain example, and competition for resources exists between Treatments.

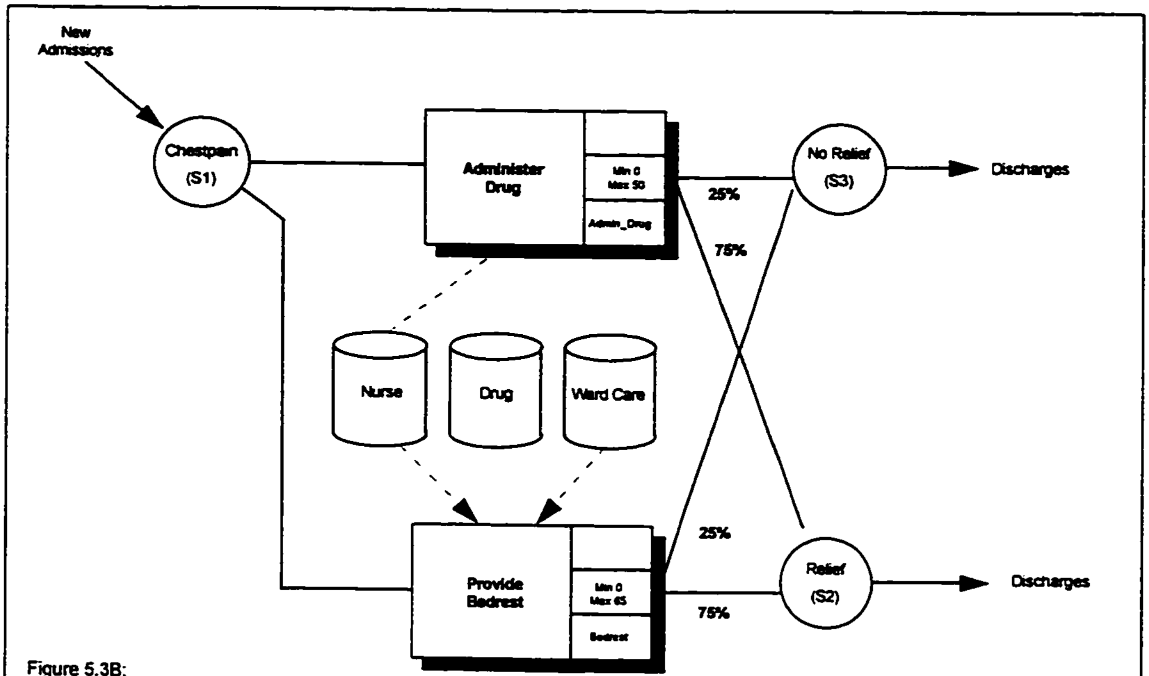

Figure 5.3B:
The Chest Pain Models

The chest pain example is developed into a multi-stage Patient Flow Model capturing simplified treatment protocols for the treatment of chest pain. The chest pain example tests the ability of the Patient Flow Model to select among alternative clinical pathways (each of which has the same prognosis) based on the availability and cost of the resources needed to provide treatment (or other criteria as defined by the model designer.) While the ability to select between alternative clinical pathways had been developed at the conceptual level, the chest pain prototype was the first computerized test of whether the Patient Flow Model could identify clinical pathways meeting pre-specified optimisation objectives.

The chest pain example was implemented using Excel 5.0 and was initially operationalised using the Excel Solver. Thirteen versions of the chest pain prototype were developed during which various strategies to operationalise conceptual components of the costing process were explored. The chest pain example provided an excellent platform with which to explore the generation of financial reports to accompany the operational information generated by the model.

The chest pain prototypes provided three important learnings. First, the simple process of "scaling up" the tetanus example to include multiple pathways and shared Resource consumption by Treatments resulted in the need to re-evaluate the method by which data is represented in the spreadsheet. A decision was made to use a matrix approach to data storage.[12] Second, a methodology for the identification of the data necessary to design a Patient Flow Model emerged. The final version of this methodology was presented earlier in this chapter. And lastly, it was evident that the numerous constraints and relationships that exist in even a modest Patient Flow Model are difficult to manage within an spreadsheet environment.

5.4 From Prototypes to Applied Demonstration

While the tetanus and chest pain examples provided excellent platforms upon which to exercise the model, both examples are limited by the fact that while they model realistic

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[12] While the matrix approach proved successful for a short period, once large, complex models were developed even this approach failed to efficiently handle the data representation process.

situations, they are not models of an actual healthcare delivery setting. Instead, they are models developed to test the theoretical underpinnings of the Patient Flow Model. In order to demonstrate the robustness of the Patient Flow Model it is necessary to move the development of prototypes from the "lab" to the "real world." An opportunity was sought to model a live healthcare setting.

5.4.1 The Setting

A major Canadian psychiatric hospital provides the environment in which a third series of prototype models is developed. The purpose of the third set of prototype models is to explore the process by which Patient Flow Models are developed in real-world settings and to both confirm the utility of the model and to determine what limitations (if any) are inherent in the model when it is used in applied settings. As introduced in Section 5.1.2, the psychiatric hospital was selected as a source for data collection because of the variety of clinical paths followed by patients in the same program. This environmental characteristic ensured that the Patient Flow Model's ability to identify optimal clinical paths could be explored.

A healthcare program that met the following criteria was sought with the assistance of clinical providers and administrators from the hospital:[13]

Criterion 1 - The program is relatively self-sufficient within the hospital.

> A program was considered to be self-sufficient if it made use of resources that were generally dedicated to the program.

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[13] These criteria were introduced in Table 5.1B on page 166.

By selecting a program with dedicated resources, the need to distinguish between unused capacity, and capacity that is unused by the program, but will be used elsewhere in the hospital, is eliminated. Ensuring resources are dedicated to the program being studied also permits planning models to be developed that have utility to the program managers. This is because factors external to the program do not need to be taken into account when interpreting output from the Patient Flow Model.

Criterion 2 – There is interest and support from the clinical providers, the administrators, and the patients involved with the program.

Given that this was the first development of a model in a live setting (one of the purposes of which was to determine what problems arise when one attempts to build a live model), interest and support from the project sponsor is critical if the project is to sustain itself.

Criterion 3 – An easily modelled clinical protocol exists.

This would eliminate the need to extract data from medical charts.[14]

Criterion 4 – The program has patients who make minimal use of resources not assigned to the program.

Criterion 5 – Financial data is available for each of the resources used by the program.

Criterion 6 – All four treatment modalities exist (Assess, Diagnose, Treat, Monitor), and there is some degree of freedom with respect to which Clinical Pathway a patient can follow given the same initial diagnosis.

The program initially identified for the study was an Eating Disorders unit. After some discussion, this program was rejected because it failed to meet criterion #3 (there was no

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[14] Prior to modelling the psychiatric environment, a project to model an orthopaedic surgical program in an acute care hospital was initiated. Data to build the Patient Flow Model was extracted from medical charts with the assistance of Medical Records technicians. The complexity of this process led to the recommendation that treatment protocols be used instead to establish Clinical Pathways. The orthopaedic models were abandoned because the data collected demonstrated that there were limited Clinical Paths followed by patients of specific physicians. This meant that while it would be possible to build simulation-based Patient Flow Models, it would be impossible to use the models for optimisation. As a goal of this study was to explore the Patient Flow Model's optimisation capabilities, it was felt that the orthopaedic setting was a sub-optimal problem domain to study.

standardised clinical protocol) and criterion #4 (the program made use of a number of Resources also shared by programs not being modelled.)

After rejecting of the Eating Disorder program as a suitable candidate for study, a second choice was explored. This was an in-hospital therapy program that helps adult patients cope with emotional issues stemming from experiencing a past traumatic incident (or multiple traumatic incidents). A traumatic incident might be an adult, who as a child, witnessed the death of a parent in a car accident, or a soldier who experienced the horrors of war in the Gulf. The program is referred to hereafter as the *Traumatic Stress Program*. The Traumatic Stress Program provided a useful setting in which to explore the utility of the Patient Flow Model for the following reasons.

1. A clearly delineated treatment plan is followed by all patients.

2. Patients have an average length of stay of 28 days. This period is of sufficient duration to permit a wide variety of treatment paths to be followed.

3. Circular patient flows exist. Of interest to determining the robustness of the Patient Flow Model is the need to examine the impact on the model of patient flows that are not repeatedly sequential. (Most examples developed to this point have explored linear patient flows where patients are admitted in state 'A' and proceed in a forward, horizontal path through a treatment program emerging in state 'B'. The psychiatric setting provides an opportunity to explore the impact of having patients cycle through a series of treatments multiple times before emerging in state 'B'. In fact, there was interest in determining what happens if the patient emerges in state 'A'.)

4. The program is relatively self-contained within the hospital. To a large extent the program relies on dedicated resources which reduces the complexity of the modelling process because of the minimized need to account for resources that may be shared with other programs within the hospital.

5. The setting involves both constrained treatment paths (mandatory Treatments) and elective treatment paths (optional Treatments).

6. Resource constraints exist, which will exercise the Patient Flow Model's ability to search for optimal Treatment paths in the presence of finite resources.

7. The Resources involved in providing care are easily identified, and are easily quantified and valued.

8. There was strong commitment to the Patient Flow Model idea from clinical providers (psychiatrists, nursing staff, counsellors) and from administrators (program co-ordinators and executive staff within the hospital.)

The Traumatic Stress Program was an ideal setting in which to prototype the development of a Patient Flow Model application in a real-world setting. The development methodology presented in Section 5.1 was used to design a Patient Flow Model of the Traumatic Stress Program.[15]

5.4.2 Specifying the Clinical Dimension of the Traumatic Stress Program

The treatment protocols used in the Traumatic Stress Program follow a repetitive seven-day cycle, although there is some variation in the treatment protocol for patients in their first week in the program. The treatment protocols were examined to identify the various Treatments and Patient States that exist in the program. Seventy-four Treatments and sixty-three Patient States were identified. To illustrate the functionality of the Traumatic Stress models, this section focusses on activities occurring on Day 1 of the treatment cycle. It is on this day that new patients are admitted to the program, and patients who have completed the program are separated. Day 1 is always a Wednesday.

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[15] The development methodology in Section 5.1 is itself a product of the model development exercise chronicled here.

The clinical protocols in a psychiatric setting were found to be far more flexible than those found in the acute care sector. Although all patients in the program shared the same initial diagnosis,[16] treatment plans for each patient varied. Patients could be prescribed different therapies and in many cases patients are free to choose the interventions in which they wish to participate.

The various clinical pathways followed by patients on Wednesday mornings illustrates this point. Figure 5.4A shows the four relatively linear paths that can be followed by patients in the STARTING NEW WEEK State.

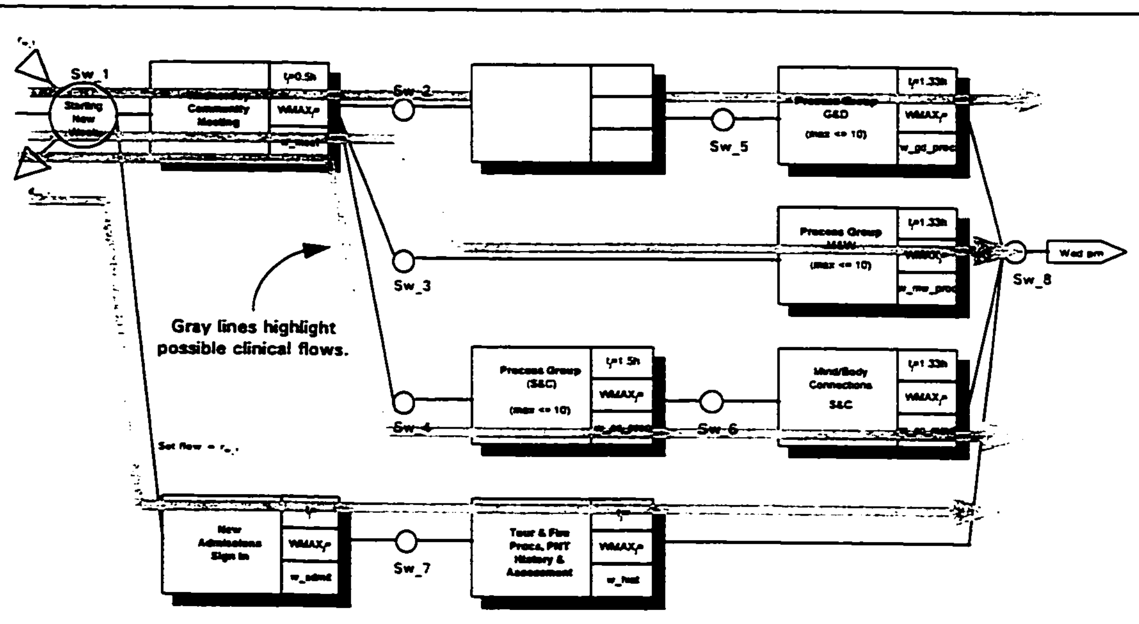

Figure 5.4A
Traumatic Stress Program (Wednesday Morning Treatments)

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16 Although many patients have co-morbid conditions (e.g., alcoholism, drug dependency), every patient in the program was there because they suffered from post traumatic stress syndrome.

The clinical pathways followed by patients are not always as easy to follow using cursory observation. Figure 5.4B shows a Patient Flow Model diagram for Wednesday afternoon. There are eight clinical pathways between lunch and dinner in this illustration.[17]

The activities of Wednesday evening complete the treatment program for Day 1 (See Figure 5.4C). The three possible routes through Wednesday evening Treatments result in a total of ninety-six possible clinical paths for Day 1 of the program.[18] The power of the linear programming routines used to solve Patient Flow Models lies in the fact that they are able to manage the many paths through the model.

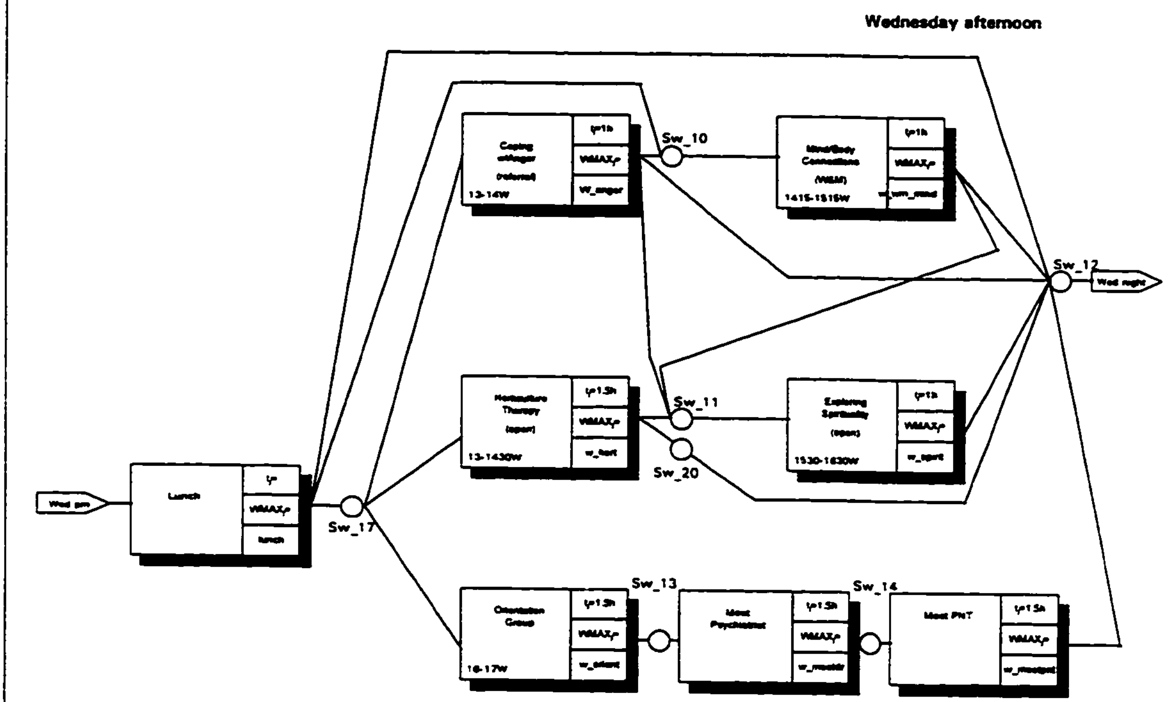

Figure 5.4B
Traumatic Stress Program (Wednesday Afternoon Treatments)

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[17] It is only coincidental that there also happens to be eight treatments.
[18] 4 morning routes * 8 afternoon routes * 3 evening routes = 96 possible combinations of treatments

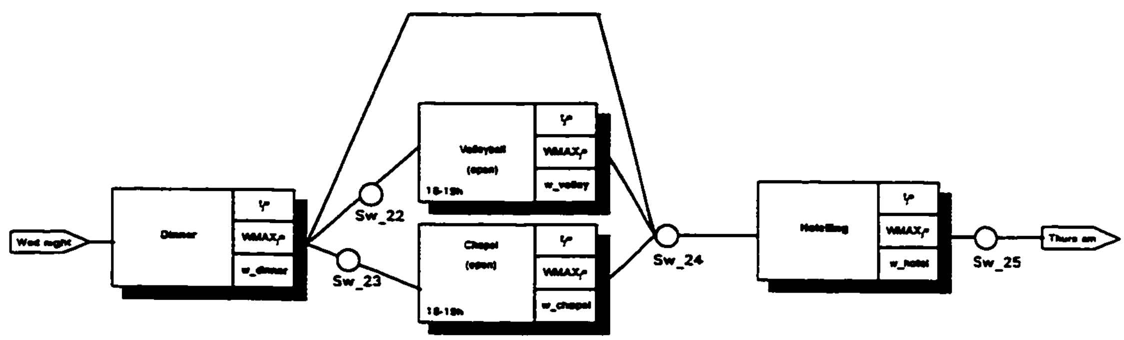

Figure 5.4C
Traumatic Stress Program (Wednesday Evening Treatments)

A number of variables are associated with Patient State Nodes and Treatment Nodes. Most of these variables define limits placed on patient flows entering and leaving nodes. Values assigned to variables for Patient State Nodes associated with Day 1 are presented in Table 5.4A. Almost all limit constraints are set to zero because patients are only admitted and separated on Wednesday mornings. This is one of the significant differences noticed between models developed for acute care settings and those developed for the psychiatric settings. Patients are admitted in a limited number of States in psychiatric settings, and patients are usually only separated at the conclusion of a clinical protocol that has a longer length of stay than found in most medical settings.

Table 5.4A								
Traumatic Stress Program Representative Examples of Patient State Nodes								
i	Description	OpenBal	Limits on Admissions		Limits on Separations		Limits on Holding in this State	
		Ei	Required RMIN*i*	Allowed RMAX*i*	Required DMIN*i*	Allowed DMAX*i*	Required FMIN*i*	Allowed FMAX*i*
Sw_1	Starting a new week	30	5	5	5	5	0	0
Sw_2	Referred to Mind/Body G&D	0	0	0	0	0	0	0
Sw_3	Process Group 1 Member	0	0	0	0	0	0	0
Sw_4	Process Group 2 Member	0	0	0	0	0	0	0
Sw_5	Process Group 3 Member	0	0	0	0	0	0	0
Sw_6	Need Mind/Body w/S&C	0	0	0	0	0	0	0
Sw_7	Newly Admitted	0	0	0	0	0	0	0
Sw_8	Hungry for Lunch (Wed)	0	0	0	0	0	0	0
Sw_9	Ready for Hort Therapy	0	0	0	0	0	0	0
Sw_10	Referred to Mind/Body W&M	0	0	0	0	0	0	0
Sw_11	Ready for Explore Spirituality	0	0	0	0	0	0	0
Sw_12	Ready for Dinner	0	0	0	0	0	0	0
Sw_13	Require Psychiatric Assmt	0	0	0	0	0	0	0
Sw_14	Require PNT Assmt	0	0	0	0	0	0	0
Sw_16	Referred to Coping w/Anger	0	0	0	0	0	0	0
Sw_17	Unoriented Patient	0	0	0	0	0	0	0
Sw_22	Interested in Volleyball	0	0	0	0	0	0	0
Sw_23	Interested in Chapel	0	0	0	0	0	0	0
Sw_24	Tired (Wed)	0	0	0	0	0	0	0
Sw_25	Hungry for Breakfast (Thurs)	0	0	0	0	0	0	0

Table 5.4B outlines Treatments provided on Wednesdays. Only the NEW ADMISSIONS SIGN IN Treatment must occur a minimum number of times.[19] Most Treatments have a maximum occurrence constraint equal to the number of patients in the program (30) or the number of patients who can attend a group therapy session (10).

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[19] This ensures all newly admitted patients follow the clinical path initiated by NEW ADMISSIONS SIGN IN.

Table 5.4B				
Traumatic Stress Program Representative Examples of Treatments				
j	Description	Duration t_j	Constraints on Treatment Occurrences Min Rqd WMIN*j*	 Max Allowed WMAX[j]
w_admit	New Admissions Sign In	1:00	5	5
w_anger	Coping with Anger	1:00	0	10
w_chapel	Chapel	1:00	0	30
w_dinner	Dinner (Wed)	1:00	0	30
w_gd_mind	Mind/Body Connections G&D	1:00	0	10
w_gd_proc	Process Group G&D	1:20	0	10
w_hist	New Admission Tour	1:00	0	5
w_hort	Horticulture Therapy	1:30	0	10
w_hotel	Wed Evening Hotelling	10:00	0	30
w_lunch	Lunch (Wed)	1:00	0	30
w_meet	Wed Community Mtg	0:30	0	30
w_meetdr	Meet Psychiatrist	1:30	0	5
w_meetpnt	Meet Prime Nurse Therapist	1:30	0	5
w_mw_proc	Process Group M&W	1:20	0	30
w_orient	Orientation	1:30	0	5
w_sc_mind	Mind/Body Connections S&C	1:00	0	30
w_sc_proc	Process Group S&C	1:30	0	30
w_spirit	Exploring Spirituality	1:00	0	30
w_volley	Volleyball	1:00	0	30
w_wm_mind	Mind/Body Connections W&M	1:00	0	30

Flow through a Patient Flow Model is controlled by values set for Treatment Distribution and Acquisition factors[20] and by decisions made by the solution engine with respect to flows following unconstrained paths in the model. Treatment Distribution Factors for Treatments occurring on Wednesday appear in Table 5.4C.

[20] Chapter 3 discussed how Distribution and Acquisition factors can also be established for Patient State Nodes in situations where this is needed to properly reflect the healthcare environment.

Table 5.4C		
Treatment Distribution Factors (β) for Selected Treatments in the Traumatic Stress Program		
Treatment	Downstream Patient State Node	Trmt Distribution Factor β
Wed Community Mtg	Sw_2 Referred to Mind/Body G&D	0.33
	Sw_3 Process Group 1 Member	0.33
	Sw_4 Process Group 2 Member	0.34
Lunch (Wed)	Sw_12 Ready for Dinner	0.10
	Sw_10 Referred to Mind/Body W&M	0.05
	Sw_17Ready for Afternoon Treatments	0.85
Coping with Anger	Sw_10 Referred to Mind/Body W&M	0.30
	Sw_12 Ready for Dinner	0.60
	Sw_11 Ready for Explore Spirituality	0.10
Horticulture Therapy	Sw_11 Ready for Explore Spirituality	0.10
	Sw_12 Ready for Dinner	0.90
Mind/Body Connections W&M	Sw_12 Ready for Dinner	0.85
	Sw_11 Ready for Explore Spirituality	0.15
Dinner	Sw_24 Tired (Wed)	0.40
	Sw_22 Interested in Volleyball	0.35
	Sw_23 Interested in Chapel	0.25
All other Wednesday Treatments have only one exit arc. (Betas therefore = 1.0)		

5.4.3 Specifying the Resource Dimension of the Traumatic Stress Program

Thirty-seven classes of Resources are used by the Traumatic Stress program. Cost and availability information for these Resources is extracted from financial reporting documents, payroll records, and budget plans. A demonstration Resource Network reflecting representative Resources used to support Treatments provided on Wednesday afternoons is presented in Figure 5.4D.

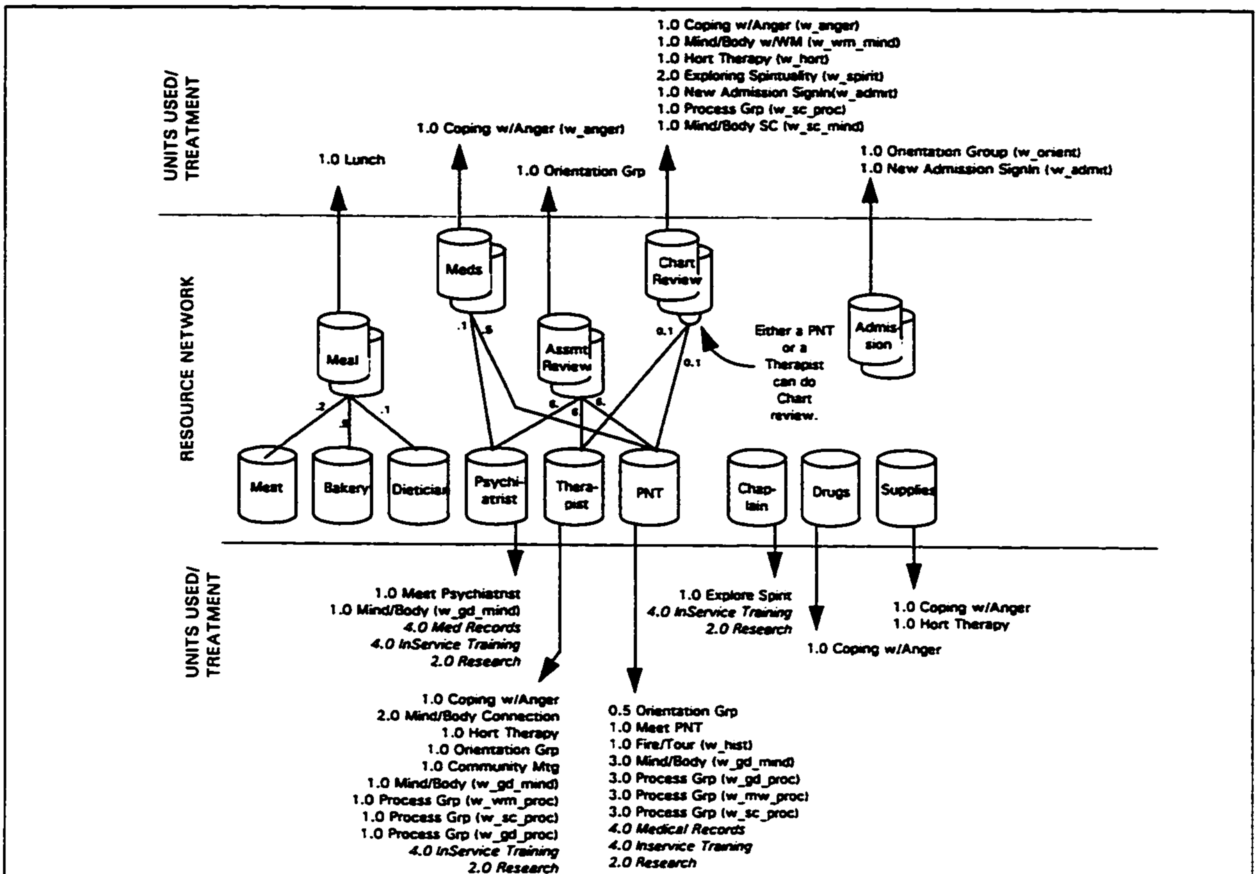

Figure 5.4D
Traumatic Stress Program Resource Network (Wednesday Afternoon Treatments

This illustrative example reflects a network consisting on of nine Resources and five Resource Packages. The explicit modelling of the non-Treatment activities required to assemble the Resource Packages has been suppressed. The arrow heads leaving each Resource or Resource Package lead to a list indicating the Treatments requiring the Resource/Resource Package. The quantity of each Resource or Resource Package used by each Treatment is also shown. Figure 5.4D (the Resource Network) should be examined in conjunction with Figure 5.4B (the matching Clinical Network for Wednesday afternoon.) (See page 192.)

MIS Code	Resource	Unit of Meas.	Res. Behaviour	Resource Type	Open Bal E(k)	Acquis. Quan Q(k)	Acquis. Cost A(k)	Unit Cost	Must Buy SMIN(k)	Max Buy SMAX(k)
Table 5.4D										
Representative Resources Used in the Patient Flow Model[21]										
R_45010	Meat, Fish, Poultry	kg	C	Patient	50	50	$ 100	$ 2.00	0	100
R_45040	Bakery Products	loaf	C	Patient	0	30	$ 100	$ 3.33	0	100
R_RD_35010	Dieticians	hr	P	Patient	0	40	$ 1,000	$ 25.00	0	100
R_PSY_35010	Psychiatrists	hr	P	Program	0	40	$ 2,700	$ 67.50	1	100
R_THP_35010	Therapists	hr	P	Program	0	40	$ 1,200	$ 30.00	0	100
R_PNT_35010	PNT (Prime Nurse)	hr	P	Program	0	40	$ 600	$ 15.00	0	100
R_CHA_35010	Chaplain	hr	P	Program	0	40	$ 900	$ 22.50	0	100
R_46550	Drugs	dose	C	Patient	0	40	$ 50	$ 1.25	0	100
R_49510	Supplies - General	case	C	Patient	0	1	$ 100	$ 100.00	0	100

Table 5.4D provides data on the Resources used on Wednesday afternoon. A variety of Resource types are represented in this table. These include Resources that *must* be purchased during the planning period, whether or not there is demand for the Resource. (The psychiatrist Resource is an example.) There are also Resources that are purchased in quantities much larger than the quantity in which they are consumed. (Bakery products are an example.) And both Consumable Resources (e.g., Supplies-General) and Persistent Resources (e.g., Therapists) are represented. The presence of persistent Resources that are assembled into Packages which are attached to patients using either treatment-related or encounter-related drivers means that, should these Resources not be fully used, unused capacity costs will be calculated by the model.

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21 Certain data has been altered from that gathered in the research so as not to disclose confidential financial data belonging to the test site.

5.4.4 The Reporting Flexibility of the Patient Flow Model

One of the strengths of the Patient Flow Model is that the model does not force users to subscribe to a particular paradigm with respect to financial reporting. The flexibility of the Patient Flow Model allows users to generate information using financial, clinical and Resource data in *whatever manner best meets the needs of the decision-maker*. This is an important feature of the Patient Flow Model.

For example, users who do not want to specifically account for the cost of unused capacity are free to do so. The cost of unused capacity can either be respected or ignored in the presentation of results. Similarly, decision-makers who need to view costs from an activity-based perspective are able to do so. And users who do not feel an activity-based approach meets their needs are able to generate information that focuses on what costs were incurred rather than on what caused costs to be incurred.

In the context of the Patient Flow Model, these different (but equally valid) means of presenting the same financial information are called *user views*. The user view concept, and its application to the Patient Flow Model is explored in Section 4.7.

The following two sections present output generated by the prototype model developed for the Traumatic Stress Program. Each of the outputs represents a user view of the much larger pool of data and information maintained for a Patient Flow Model.

5.4.5 Generating Clinical Flow Information[22]

This section presents examples of output that can be generated by a Patient Flow Model. The focus is on clinical flows. There are 96 possible routes that can be followed by patients on Wednesday alone.

Table 5.4E shows Treatment counts (w_j) experienced when 25 patients are in the condition STARTING NEW WEEK and five new patients are admitted in this condition. (This is the normal patient load profile for a Wednesday.) In order to focus attention on the clinical flows, an objective function that is not influenced by resource costs or availability constraints is used. Two objectives are explored. The first seeks to identify the combination of Treatments that will result in patients receiving the most Treatment[23]. The second identifies a Patient Flow Model profile that minimises the length of time patients are in Treatment. In both cases, the model is defined to ensure that patients receive a full day of treatment.[24]

Table 5.4E shows how the Patient Flow Model successfully identifies clinical paths that result in either minimising or maximising the length of the treatment program. When presented

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22 Production Model SURV15K.XLS used to generate results in this section.
23 Measured very crudely in this illustrative example by using the duration of the Treatment activity as a proxy for the amount of treatment received.
24 i.e., all patients beginning the day are required to be in the "Ready for Dinner" state by the end of the day.

with a choice after lunch of having patients participate in COPING WITH ANGER (w_anger, 1hr), MIND/BODY CONNECTIONS (w_wm_mind, 1hr) or HORTICULTURE THERAPY (w_hort, 1.5hr), the model correctly identifies that the HORTICULTURE THERAPY Treatment should be bypassed if the objective is to minimise Treatment time.[25] And the opposite is also true. When the goal is to maximise the amount of therapy offered, HORTICULTURE THERAPY is favoured, resulting in 22 hours of the HORTICULTURE THERAPY being offered.

Table 5.4E

Traumatic Stress Program
Treatment Count Values When Goal is to Minimize/Maximize Treatment Time

Treatment j	Minimise t(j) w(j)	Maximise t(j) w(j)
Tuesday Hotelling (t_hotel)	0.00	0.00
Wed Community Mtg (w_meet)	25.00	25.00
Mind/Body Connect (w_gd_mind)	8.50	8.50
Process Group S&C (w_sc_proc)	8.25	8.25
New Admissions SignIn (w_admit)	5.00	5.00
Tour & Fire (w_hist)	5.00	5.00
Process Grp (G&D) (w_gd_proc)	8.50	8.50
Process Grp (M&W) (w_mw_proc)	8.25	8.25
Mind/Body (S&C) (w_sc_mind)	8.25	8.25
Lunch (w_lunch)	30.00	30.00
Coping w/Anger (w_anger)	22.00	0.00
Mind/Body (w_wm_mind)	6.60	0.00
Hort Therapy (w_hort)	0.00	22.00
Explore Spirituality (w_spirit)	3.19	15.40
Orientation (w_orient)	5.00	5.00
Meet Psych (w_meetdr)	5.00	5.00
Meet PNT (w_meetpnt)	5.00	5.00
Total Patients Receiving Care	30	30
Total Care Providing Hours Used:	161.34	174.65

[25] An additional choice after lunch is to participate in Orientation Group (w_orient). This Treatment, however, is required to have a Treatment Count (wj) equal to the number of newly admitted patients, and as such is not a free arc in the network.

To further demonstrate the Patient Flow Model's ability to identify routes that best satisfy the objective function provided, a constraint is placed on the COPING WITH ANGER Treatment so that only three patients can receive the Treatment. It has already been seen that when the objective is to minimise treatment times, the COPING WITH ANGER Treatment forms part of the favoured treatment plan. With 27 patients in the READY FOR AFTERNOON TREATMENT state, the model is forced to search for a less optimal route in order to ensure that all patients receive care. Table 5.4F shows how constraining the ANGER Treatment to three patients results in the remaining 19 patients being routed through the more lengthy HORTICULTURE Treatment.

Table 5.4F

Traumatic Stress Program
Treatment Count Values
Goal: Minimise Treatment Time
Constrained: Anger Treatment Limited to 3 Patients

j	Minimise t(j) w(j)
Tuesday Hotelling (t_hotel)	0.00
Wed Community Mtg (w_meet)	25.00
Mind/Body Connect (w_gd_mind)	8.50
Process Group S&C (w_sc_proc)	8.25
New Admissions SignIn (w_admit)	5.00
Tour & Fire (w_hist)	5.00
Process Grp (G&D) (w_gd_proc)	8.50
Process Grp (M&W) (w_mw_proc)	8.25
Mind/Body (S&C) (w_sc_mind)	8.25
Lunch (w_lunch)	30.00
Coping w/Anger (w_anger)	3.00
Mind/Body (w_wm_mind)	0.90
Hort Therapy (w_hort)	19.00
Explore Spirituality (w_spirit)	13.74
Orientation (w_orient)	5.00
Meet Psych (w_meetdr)	5.00
Meet PNT (w_meetpnt)	5.00
Total Patients Receiving Care	30
Total Care Providing Hours Used:	161.34

The Patient Flow Model automatically produces information on the flow of patients along each clinical arc in the network. Information on flows for the scenario just presented appears in Table 5.4G.

While these optimisations generate valid results, it is appreciated that a goal of minimising or maximising Treatment time in this setting is an objective function that serves only to visually validate the functionality of the Patient Flow Model. Because the Traumatic Stress program is residential in nature, all patients remain in the program for the same length of time irrespective of the amount of Treatment received.

In contrast, in acute healthcare settings, seeking to minimise total Treatment time is an objective function of considerable interest. Care must be exercised, however, when specifying an objective function such as minimising Treatment time. The model designer must ensure that all possible routes offer the same prognosis.

5.4.6 Generating Resource Flow Information

Section 5.4.5 presented information generated by the Clinical Network. This section focusses on Patient Flow Model information generated by the Resource Network. The data used to populate the model is identical.

Table 5.4G

Traumatic Stress Program
Flow Values for Clinical Pathways

	From Patient State	To w_meet	To w_admit	To w_gd_mind	To w_sq_proc	To w_hist	To w_gd_proc	To w_mw_proc	To w_sq_mind	To w_lunch	To w_anger
Sw_1	Starting a new week	25.00	5.00								
Sw_2	Referred to Mind/Body w/G&D			8.50							
Sw_3	Process Group 1 Member							8.25			
Sw_4	Process Group 2 Member				8.25						
Sw_5	Process Group 3 Member						8.50				
Sw_6	Need Mind/Body w/S&C								8.25		
Sw_7	Newly Admitted					5.00					
Sw_8	Hungry for Lunch (Wed)									30.00	
Sw_9	Ready for Hort Therapy										
Sw_10	Referred to Mind/Body W&M										
Sw_11	Ready to Explore Spirituality										
Sw_12	Ready for Dinner										
Sw_13	Require Psychiatric Assmt										
Sw_14	Require PNT Assmt										
Sw_16	Referred to Coping w/Anger										0.00
Sw_17	Ready for Afternoon Tx										3.00
	Total Inflows from Previous States	25.00	5.00	8.50	8.25	5.00	8.50	8.25	8.25	30.00	3.00

	From Patient State	To w_wm_mind	To w_hort	To w_spirit	To w_orient	To w_meetdr	To w_meetpnt	To w_dinner	Leaving s(t)
Sw_1	Starting a new week								30
Sw_2	Referred to Mind/Body w/G&D								8.5
Sw_3	Process Group 1 Member								8.25
Sw_4	Process Group 2 Member								8.25
Sw_5	Process Group 3 Member								8.5
Sw_6	Need Mind/Body w/S&C								8.25
Sw_7	Newly Admitted								5
Sw_8	Hungry for Lunch (Wed)								30
Sw_9	Ready for Hort Therapy		0.00						0
Sw_10	Referred to Mind/Body W&M	2.40							2.4
Sw_11	Ready to Explore Spirituality			12.91					12.91
Sw_12	Ready for Dinner							30.00	30
Sw_13	Require Psychiatric Assmt					5.00			5
Sw_14	Require PNT Assmt						5.00		5
Sw_16	Referred to Coping w/Anger								0
Sw_17	Ready for Afternoon Tx		17.50		5.00				25.5
	Total Inflows from Previous States	2.40	17.50	12.91	5.00	5.00	5.00	30.00	187.56

The cost to assemble the Resource Packages used on Wednesday afternoon can be determined by combining data found in Table 5.4D with data found in Figure 5.4D. The resulting information is presented in Table 5.4H. The Wednesday afternoon activities include Resource Packages that are attached to patients on both a treatment basis (e.g., MEDS) and an encounter basis (e.g., ASSESSMENT REVIEW)

Table 5.4H

Representative Resource Packages Used in the Traumatic Stress Patient Flow Model

Resource Pkg	Assembled Using	Quan	Unit Cost	Extension
Meal	Meat, Fish, Poultry	.2 kg	$2.00	$0.40
	Bakery	.5 loaf	3.33	1.66
	Dietician	.1 hr	25.00	2.50
			Cost of Meal Package	$4.56
Meds	Psychiatrist	.1 hr	$67.50	$6.75
	PNT	.5 hr	15.00	7.50
			Cost of Meds Package	$14.25
Assessment Review	Psychiatrist	6 hr	$67.50	$405.00
	Therapists	6 hr	30.00	180.00
	PNTs	6 hr	15.00	90.00
			Cost of Assessment Review Package	$675.00
Chart Review	Therapist	.1 hr	$30.00	$3.00
			Cost of Chart Review Pkg (when assembled using Therapist)	$3.00
Chart Review	PNT	.1 hr	$15.00	$1.50
			Cost of Chart Review Pkg (when assembled using PNT)	$1.50
Admission	Psychiatrist	1 hr	67.50	67.50
	Therapist	1 hr	30.00	30.00
			Cost of Admission Package	$97.50

Using the same patient loading profile as was used in the previous section (25 continuing patients + 5 new admissions), the Patient Flow Model reports the Resource use and spending information presented in Figure 5.4I. An objective function designed to minimise the use of Resources while maximising the number of patients treated is used in this example. All 30 patients receive care.

Table 5.4I

Traumatic Stress Program
Resource Cost Information
Goal: Maximise use of available resources
Constrained: All patients must be treated.

Resource Consumption Profile Resource	Cost of Resource Used	Paid for but not Needed	Total Resource Cost	Amt Spent on Resource
Meat, Fish, Poultry	$12	-	$12	$0
Bakery Products	50	-	50	100
Dietitians	75	$925	1,000	1,000
Psychiatrists	4,286	1,114	5,400	5,400
Therapists	3,990	810	4,800	4,800
PNT (Prime Nurse Therapists)	2,434	566	3,000	3,000
Chaplain	463	437	900	900
Drugs	-	-	-	-
Supplies - General	2,050	-	2,050	2,100
	$13,360	$3,852	$17,212	$17,300
Number of Patients Treated	30.00 (measured as patients completing day's Treatments - i.e., leaving State Sw_12)			

The *Cost of Resource Used* column provides information on the value of Resources actually used to provide care. The Patient Flow Model has the ability to identify Resources that are purchased but not used. The *Paid for But Not Needed* column reflects the value of Resources acquired and paid for, but not needed to provide care. In this example, these amounts reflect the value of unused Persistent Resources, such as the difference between salaries paid to Psychiatrists and Therapists and the value of the hours actually used to provide care.

The final column (*Amt Spent on Resource)* provides information on spending levels. Although $12 of MEAT, FISH AND POULTRY is reported to have been used, nothing was spent on this Resource. Inspection of the complete model would identify that the required quantity of MEAT, FISH AND POULTRY was in stock at the beginning of the planning period, and therefore additional spending was not required. *Amount Spent on Resources* reflects the cash cost of acquiring the Resource units needed during the planning horizon. This amount exceeds *Total Resource Cost* whenever a Resource must be purchased in quantities greater than the units in which the Resource is used. In these cases, the excess is either treated as the cost of excess capacity (in the case of Persistent Resources) or is included in the value of closing inventories (as is the case for Consumable Resources.)

Given that 30 patients have received care, many views of the cost of providing care can be developed. Four such views are presented below.

Fully Loaded Average Cost per Patient[26] (Total Resource Cost / # patients treated)	$573.73
Actual Average Cost per Patient (Cost of Resources Actually Used / # patients treated)	$445.34
Sustaining Costs (net of unused capacity) per patient	$406.34
Sustaining Costs (incl. unused capacity) per patient	$437.17

The design of the Patient Flow Model allows model users to arrange data in a myriad of ways in order to report performance information not easily determined using most accounting information systems. For example, the activity-based nature of the Patient Flow Model permits

[26] Based on treating 25 in-program patients and 5 new admissions. Resource data used to generate these results appears in Figure 5.4I.

the calculation of the cost of providing the various Treatment activities to be determined. It is also possible to determine the cost of assembling the Resource Packages needed to provide the Treatments, and by extension, to determine the cost of performing the non-Treatment activities required to assemble the Resource Packages. A Treatment Cost Report based on 30 patients is presented in Figure 5.4J.

Table 5.4J

Traumatic Stress Program
Treatment Cost Report
(total patient volume = 30)

count w(j)	Treatment j	Unit Cost
30.00	Lunch (w_lunch)	4.57
0.00	Coping w/Anger (w_anger)	147.00
1.50	Mind/Body (W&M) (w_wm_mind)	61.50
20.50	Hort Therapy (w_hort)	131.50
14.58	Explore Spirituality (w_spirit)	25.50
5.00	Orientation (w_orient)	810.00
5.00	Meet Psych (w_meetdr)	67.50
5.00	New Admissions SignIn (w_admit)	99.00
5.00	Tour & Fire (w_hist)	15.00
25.00	Wed Community Mtg (w_meet)	30.00
8.50	Mind/Body Connect (w_gd_mind)	142.50
8.50	Process Grp (G&D) (w_gd_proc)	75.00
8.25	Process Grp (M&W) (w_mw_proc)	75.00
8.25	Process Grp (S&C) (w_sc_proc)	76.50
8.25	Mind/Body (w_sc_mind)	1.50
5.00	Meet PNT (w_meetpnt)	15.00

The design of the Patient Flow Model ensures that the cost of providing a Treatment does not change with volume. This can be shown by repopulating the model used to generate results in this section with a scenario requiring 25 new patients be admitted (instead of only five) to join the 25 patients already in the program. The count values (w_j) change for many Treatment activities, but the cost of providing individual Treatments remains unchanged from that presented in Figure 5.4J.

Table 5.4K		
Traumatic Stress Program Treatment Cost Report (total patient volume = 50)		
count w(i)	Treatment i	Unit Cost
50.00	Lunch (w_lunch)	4.57
0.00	Coping w/Anger (w_anger)	147.00
2.50	Mind/Body (W&M) (w_wm_mind)	61.50
17.50	Hort Therapy (w_hort)	131.50
12.62	Explore Spirituality (w_spirit)	25.50
25.00	Orientation (w_orient)	810.00
25.00	Meet Psych (w_meetdr)	67.50
25.00	New Admissions SignIn (w_admit)	99.00
25.00	Tour & Fire (w_hist)	15.00
25.00	Wed Community Mtg (w_meet)	30.00
8.50	Mind/Body Connect (w_gd_mind)	142.50
8.50	Process Grp (G&D) (w_gd_proc)	75.00
8.25	Process Grp (M&W) (w_mw_proc)	75.00
8.25	Process Grp (S&C) (w_sc_proc)	76.50
8.25	Mind/Body (w_sc_mind)	1.50
25.00	Meet PNT (w_meetpnt)	15.00

While the cost of providing individual treatments remains unchanged, the average cost of providing care does change because the profile of resources needed to sustain the new patient load differs from what was required to treat only 30 patients.

Fully Loaded Average Cost per Patient[27] (Total Resource Cost / # patients treated)	$753.07
Actual Average Cost per Patient (Cost of Resources Used / # patients treated)	$663.98
Sustaining Costs (net of unused capacity)/patient	$640.58
Sustaining Costs (incl. unused capacity) / patient	$658.08

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[27] Based on treating 25 in-program patients and 25 new admissions. Resource data used to generate these results appears in Figure 5.4L.

The Patient Flow Model is able to generate detailed reports for any Clinical Path in the network. The examples in this section use an objective function that seeks to minimise Resource costs while ensuring that a) all patients receive Treatment, and b) only patients newly admitted to the program participate in the series of Treatments designed for patients in Day 1 of their Treatment. Figure 5.4L provides information regarding the Clinical Protocol followed by newly admitted patients. Note how the report verifies that the cost per patient to have patients follow this Clinical Protocol does not change even when an additional 20 patients follow this sequence of Clinical Pathways.

Table 5.4L

Traumatic Stress Program
Clinical Protocol Report - Cost & Count Information
Patient Profile: New Admission

Treatments Received	For 5 New Admissions w(j)	c(j)	For 25 New Admissions w(j)	c(j)
New Admissions SignIn (w_admit)	5.0	99.00	25.0	99.00
Tour & Fire (w_hist)	5.0	15.00	25.0	15.00
Lunch (w_lunch)	30.0	4.57	50.0	4.57
Orientation Group (w_orient)	5.0	810.00	25.0	810.00
Meet Psychiatrist (w_meetdr)	5.0	67.50	25.0	67.50
Meet PNT (w_meetpnt)	5.0	15.00	25.0	25.00
Patients Following This Protocol	5.0	$ 1011.07	25.0	$ 1011.07

In Chapter 4, it was shown that costs behave in one of four ways. These four behaviours were patient related costs, encounter related costs, program sustaining costs and facility sustaining costs. Figure 5.4M shows the cost of providing care using this framework. As reviewed on page 199 (Section 5.4.4), this presentation is simply one *user view* of the information generated by the Patient Flow Model. In addition to organising costs using the cost behaviour framework, this view also discloses the cost of unused capacity.

Table 5.4M

Traumatic Stress Program
Cost Report
(unused capacity cost disclosed)

Treatment Related Costs						
Lunch (w_lunch)	$	137				
Coping w/Anger (w_anger)	$	-				
Mind/Body (W&M) (w_wm_mind)	$	92				
Hort Therapy (w_hort)	$	2,696				
Explore Spirituality (w_spirit)	$	372				
Orientation (w_orient)	$	4,050				
Meet Psych (w_meetdr)	$	338				
New Admissions SignIn (w_admit)	$	495				
Tour & Fire (w_hist)	$	75				
Wed Community Mtg (w_meet)	$	750				
Mind/Body Connect (w_gd_mind)	$	1,211				
Process Grp (G&D) (w_gd_proc)	$	637				
Process Grp (M&W) (w_mw_proc)	$	619				
Process Grp (S&C) (w_sc_proc)	$	631				
Mind/Body (w_sc_mind)	$	12				
Meet PNT (w_meetpnt)	$	75				
Unused Capacity Costs - Patient Sustaining	$	925				
Total Patient Sustaining Costs			$	13,115		
Encounter Related Costs						
there are no encounter based costs in this eg						
Unused Capacity Costs - Encounter Sustaining	$	-				
Total Encounter Sustaining Costs			$	-		
Program Sustaining Costs						
In-service Training (prog sust'ng)	$	540				
Research (prog sust'ng)	$	300				
Unused Capacity Costs - Program Sustaining	$	2,927				
Total Program Sustaining Costs			$	3,767		
Facility Sustaining Costs						
Medical Records (facility sust'ng)	$	330				
Unused Capacity Costs - Facility Sustaining	$	-				
Total Facility Sustaining Costs			$	330		
					$	17,212

This section has presented a small sample of the reports that can be created using information generated by the Patient Flow Model. The flexibility of the Patient Flow Model ensures that model users are able to organise the results of any optimisation or simulation in a manner that best meets their decision-making requirements.

5.4.7 Comprehensive Presentation of the Traumatic Stress Program Model

Section 5.4.5 and 5.4.6 present Patient Flow Model results that are based on activities occurring on Wednesday in the Traumatic Stress Program. The Traumatic Stress Program consists of repeating cycle of seven days. Patient Flow Model networks were developed as part of this research for all seven days. This section presents a comprehensive illustration of the Patient Flow Model designed for the Traumatic Stress Program.

To assist in the presentation of the model, panels have been organised around day of treatment and time of treatment. It is important to note that this organisation is for presentation purposes only. Each panel should be imagined to connect to the next to form one large, integrated Patient Flow Model diagram.

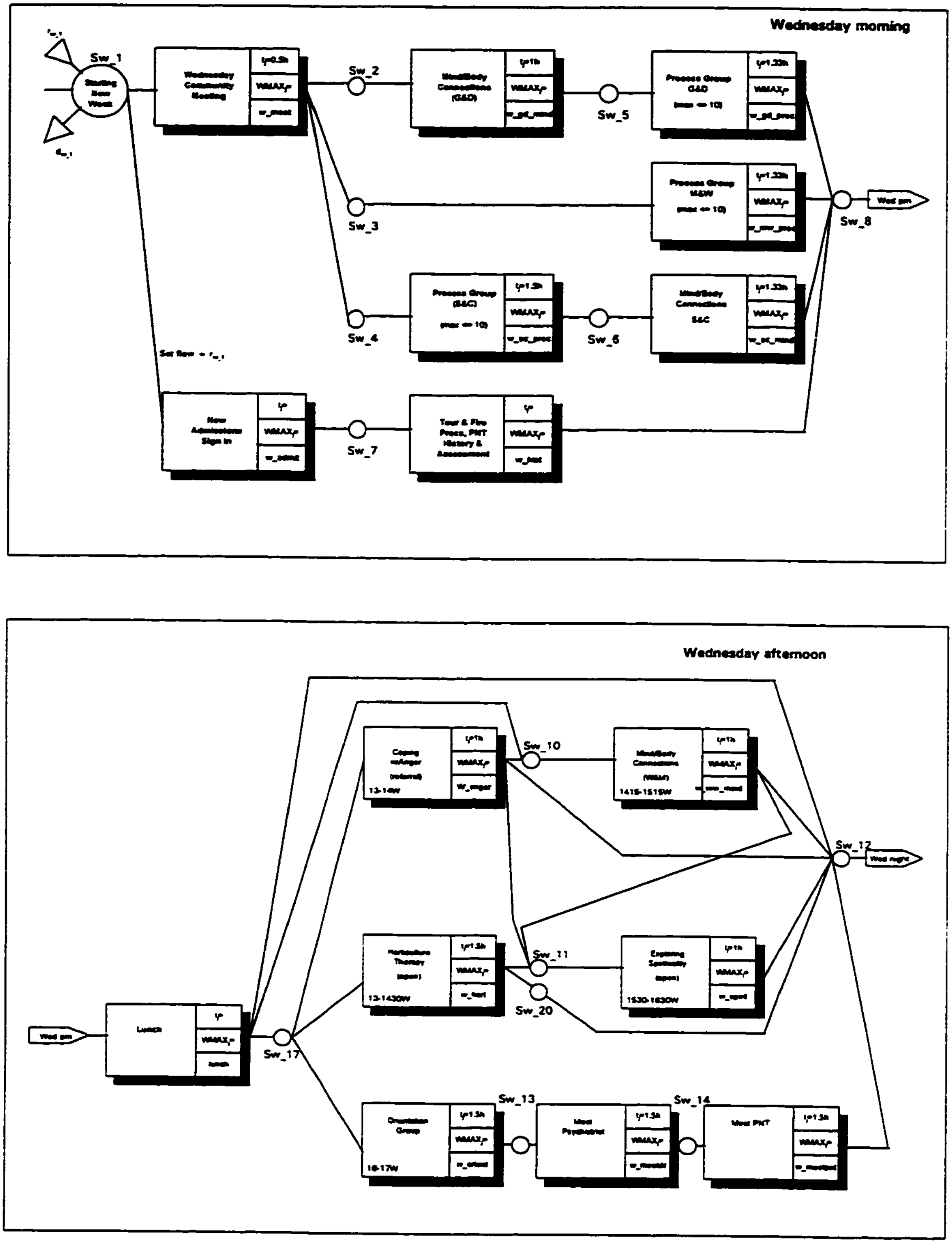

Figure 5.4E (panels 1 and 2)
Traumatic Stress Program - Clinical Network

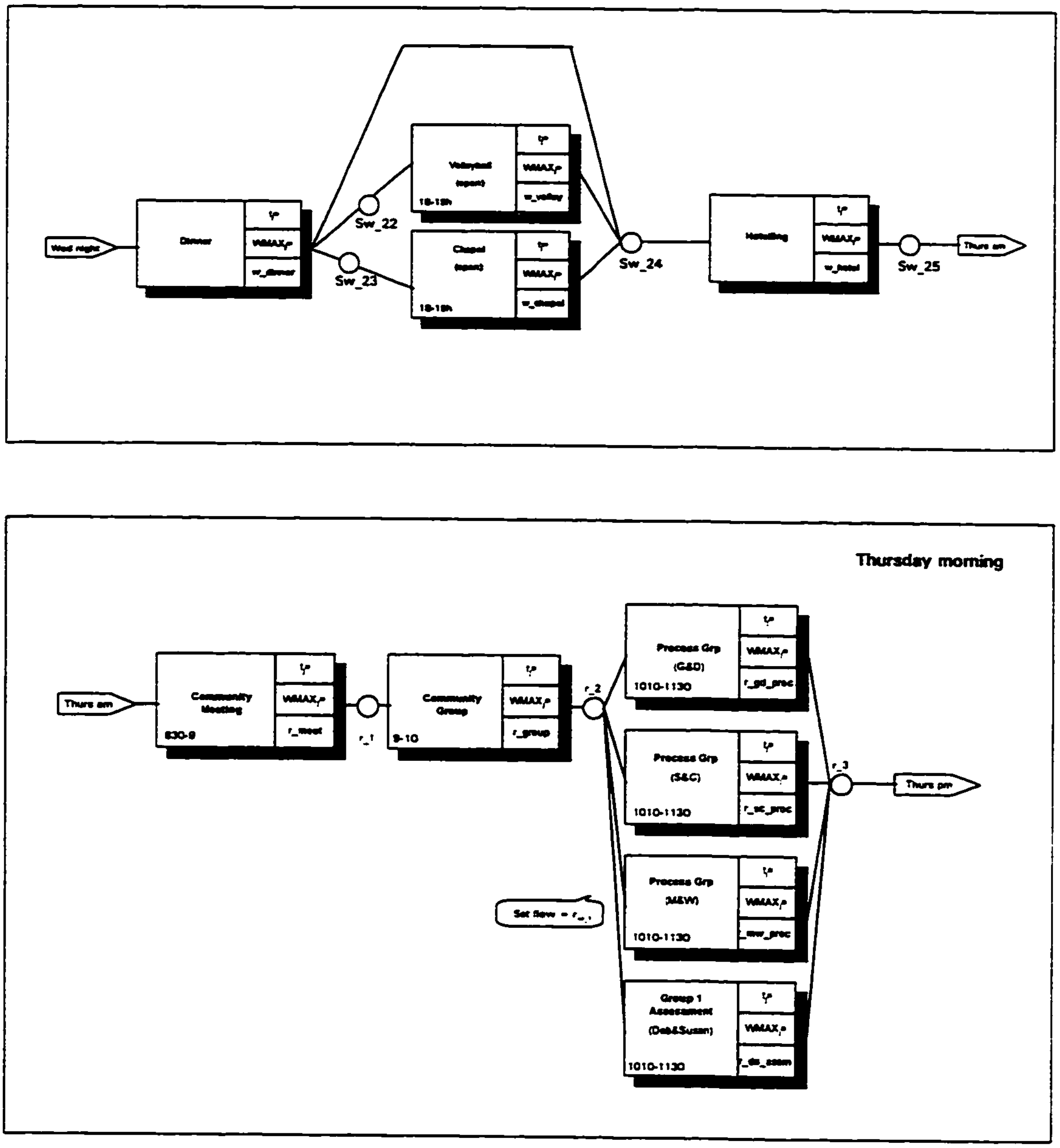

Figure 5.4E (panels 3 and 4)
Traumatic Stress Program - Clinical Network

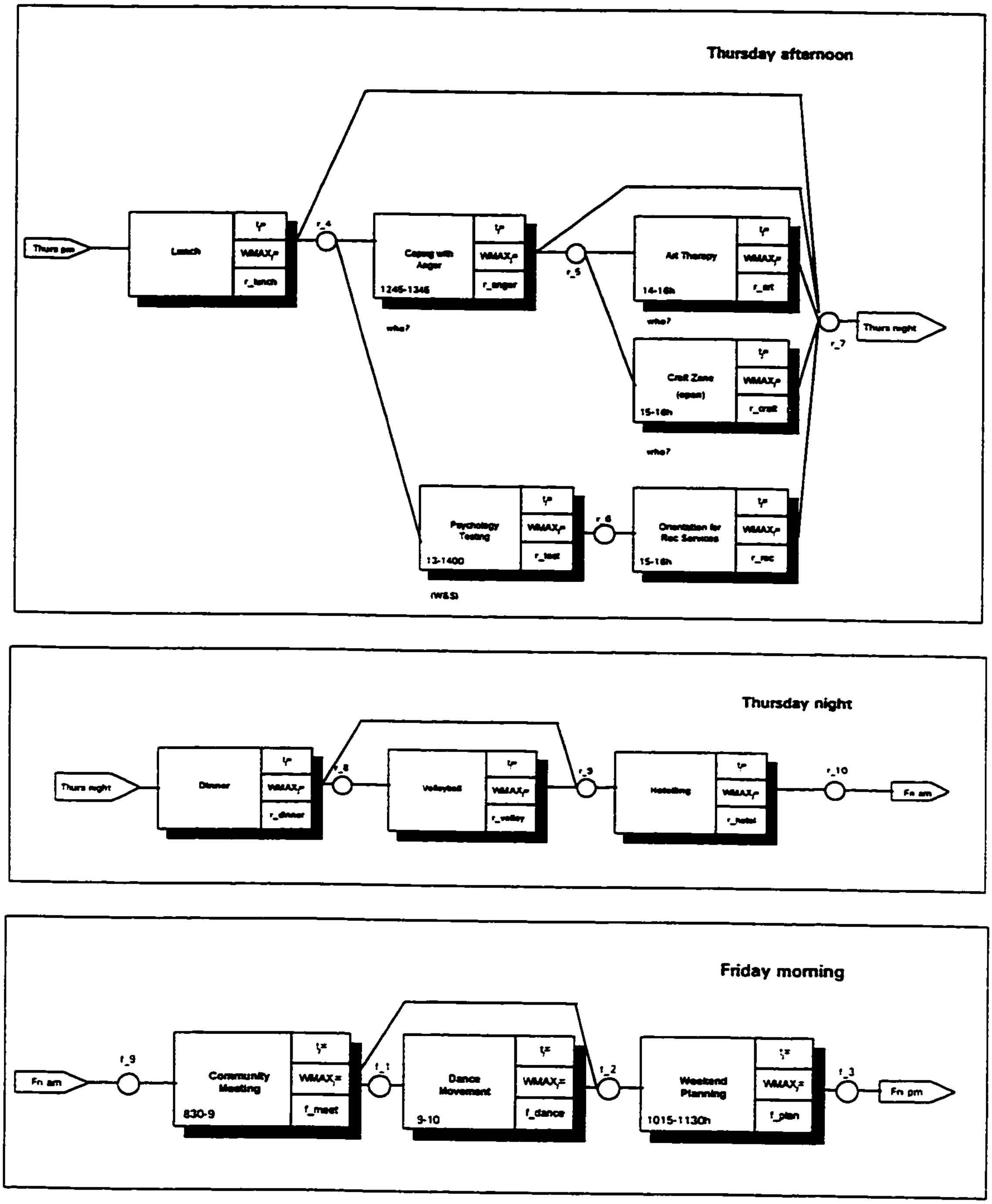

Figure 5.4E (panels 5 through 7)
Traumatic Stress Program - Clinical Network

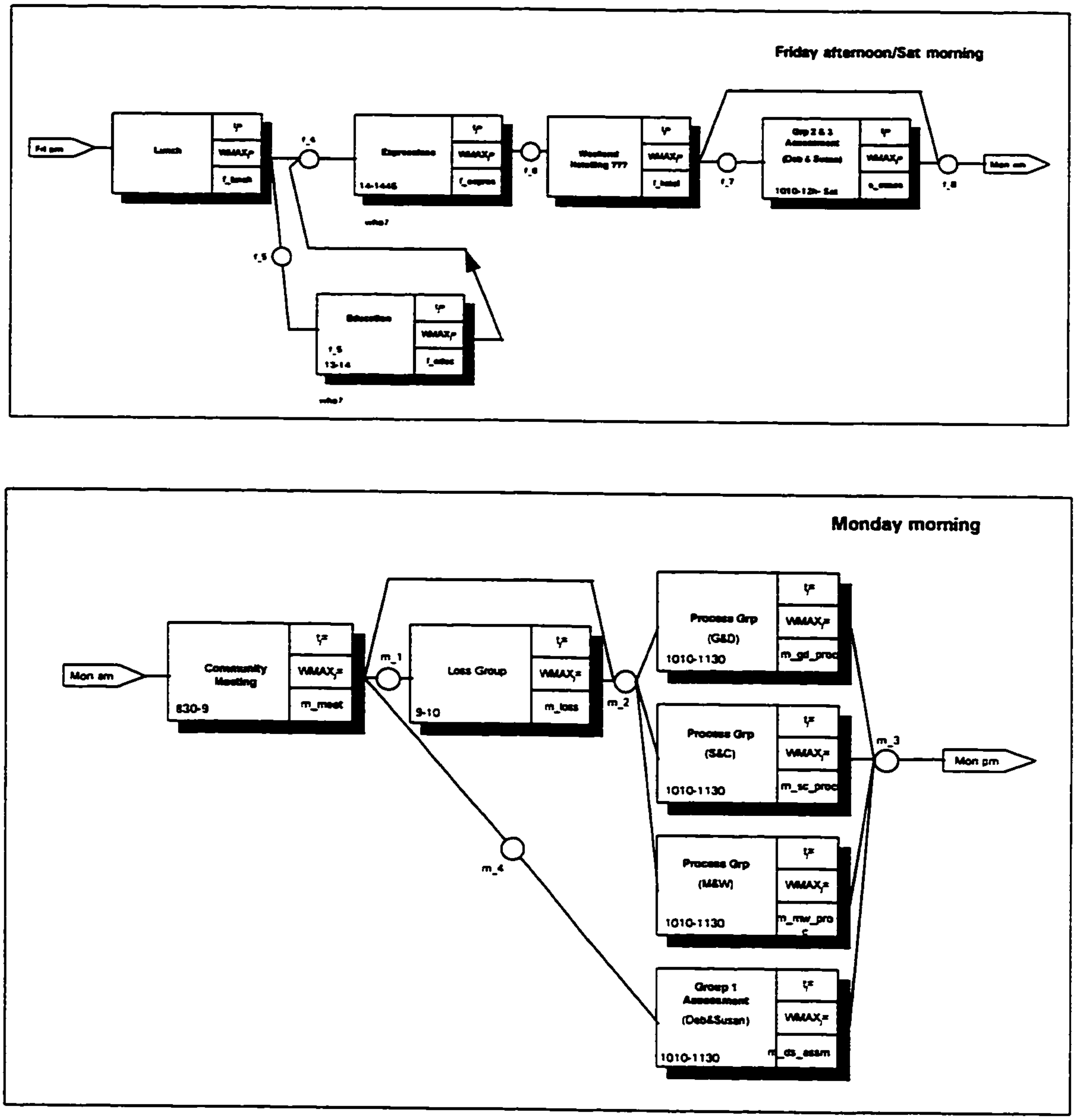

Figure 5.4E (panels 8 and 9)
Traumatic Stress Program - Clinical Network

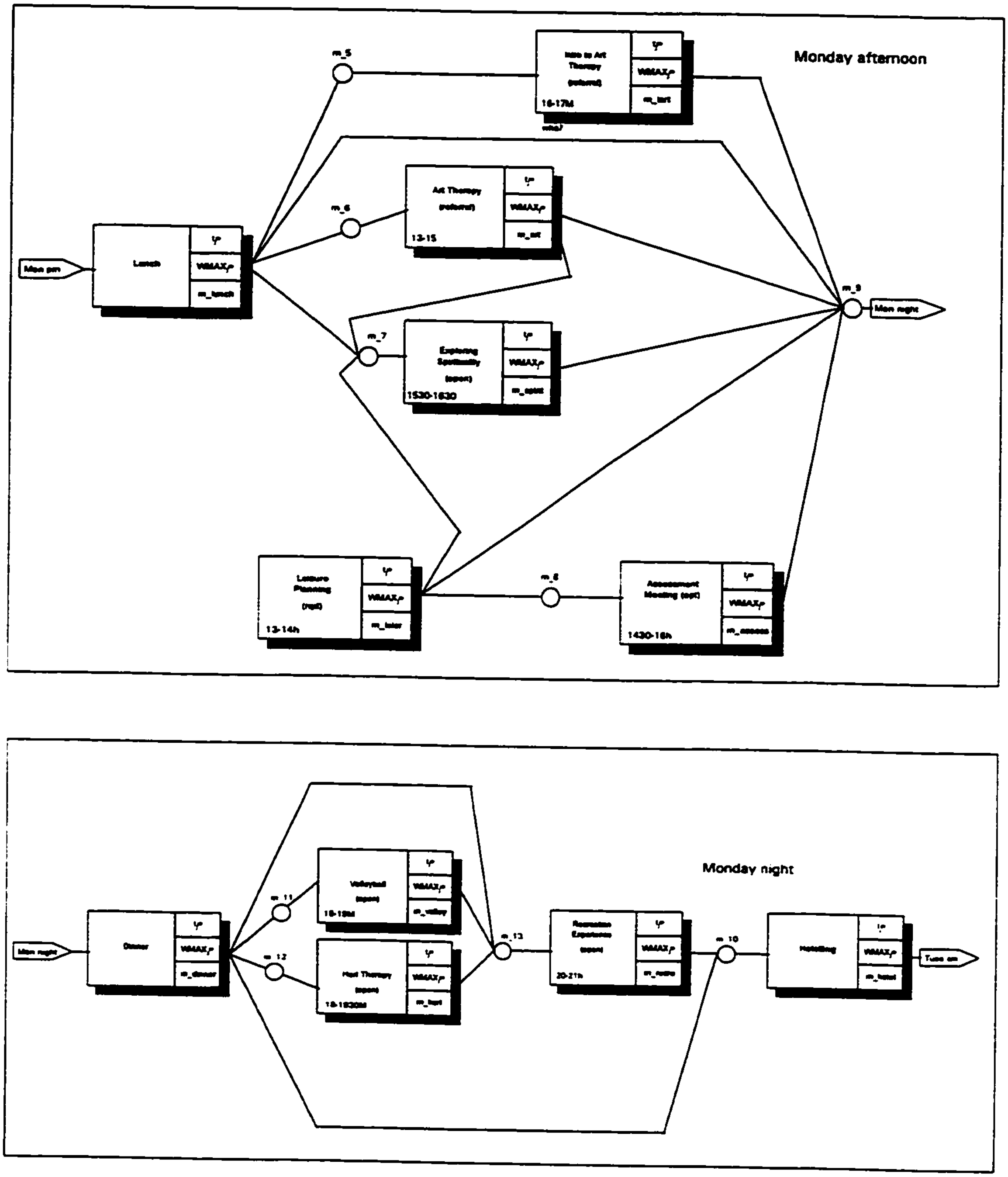

Figure 5.4E (panels 10 and 11)
Traumatic Stress Program - Clinical Network

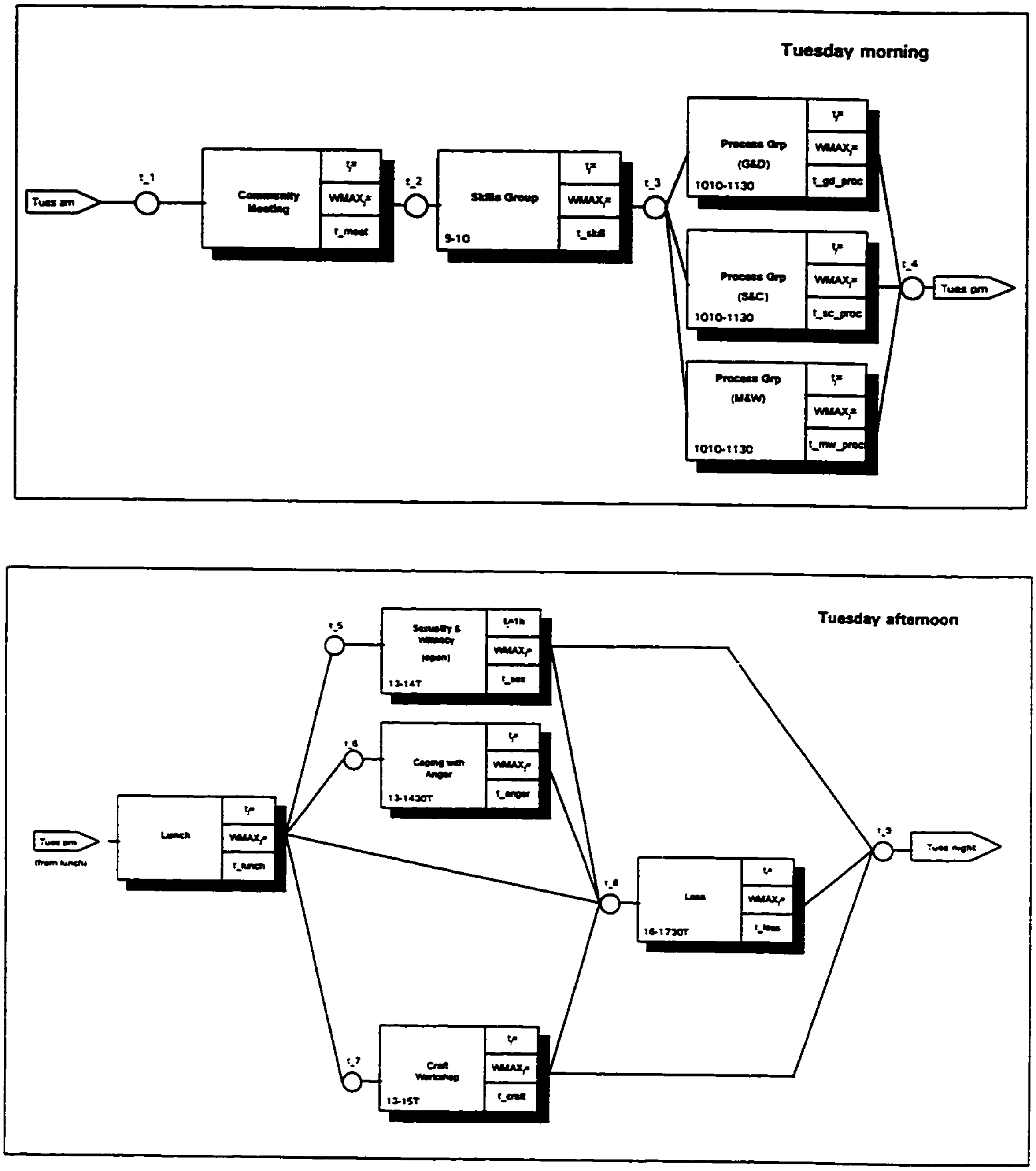

Figure 5.4E (panels 12 and 13)
Traumatic Stress Program - Clinical Network

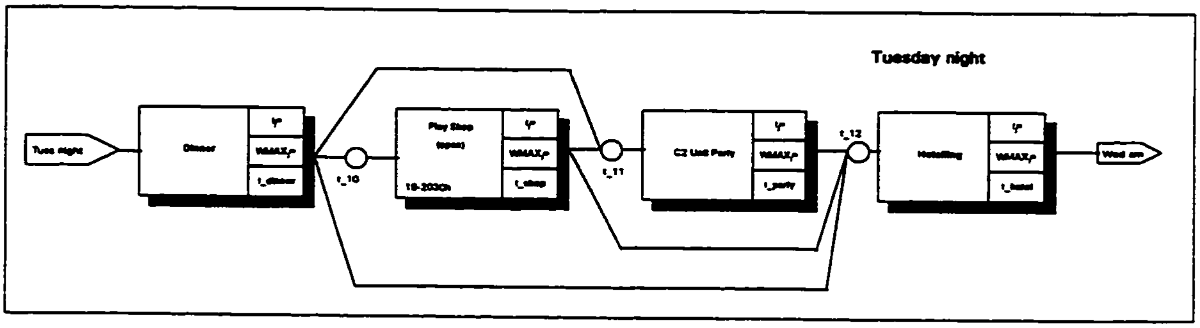

Figure 5.4E (panel 14)
Traumatic Stress Program - Clinical Network

5.4.8 Lessons Learned - Traumatic Stress Models

The Traumatic Stress models provided the first larger scale opportunity to exercise the Patient Flow Model. From this experience came a number of observations.

Models Must Easily Adapt to Changing Clinical Practices

An early lesson learned was that the implementation strategy chosen to represent data within a Patient Flow Model made it difficult to adapt the model to reflect changes in clinical practice. This limitation was recognised at the outset, but was assumed to be of minimal consequence because changes in clinical protocols occur infrequently. (i.e., Changes in clinical protocols do not occur weekly or monthly.) This limitation posed no difficulties when developing the vaccination and chest pain models. The assumption proved, however, to be completely erroneous in a psychiatric setting. In psychiatric settings, changes in the weekly treatment plans happened with considerable frequency. Alternative data representation strategies were sought to reduce the relatively inflexible representation strategies used in the vaccination and chest pain models. Experimentation demonstrated that a matrix approach to representing arcs in the network produced a model that was amenable to later changes in clinical practice or changes in the resource consumption profile. This change did introduce, however, the challenge of dealing with sparse matrices. Because the solution engine used was not capable of handling sparse matrices, care needed to be taken when defining the linear programming relationships.

Compromising Model Size in Return for a Suitable Prototyping Environment

Models developed for this research are implemented using various versions of Microsoft Excel. Excel offered an excellent interface for both capturing parameter data and for presenting the results of a Patient Flow Model scenario. Unfortunately, the solution engine that accompanies Excel is limited to 200 variables and 400 constraints. With each Patient State Node having as a part of its definition a minimum of 6 flow arcs, it did not take long before the size of the Traumatic Stress Program models exceeded the capabilities of the Solver engine. The use of alternative solution engines was explored, however, in each case the trade-offs affecting model functionality and/or interface flexibility resulted in returning to the Excel Solver.

Given that the concept behind the Patient Flow Model has now been demonstrated, the next step is to move forward and implement Patient Flow Models using tools that have a better design for the required tasks. It is suggested that the underlying database of parameter data be maintained using a database tool. With proper design, the database tool should be able to interrogate the General Ledger software used by a hospital in order to extract the data needed to populate a Patient Flow Model. The link should be somewhat straightforward as each Resource Node has an associated general ledger secondary code, and each Treatment has an associated primary general ledger code.

The data and problem definition (objective function, constraints, etc.) can then be passed to a dedicated linear programming language for solution. The resulting information can be passed back either to the database program or to an interface design program for presentation to the model user. It is anticipated that a commercial version of the Patient Flow Model will take such an approach.

5.5 Comparing the Patient Flow Model with Current Practice

This chapter has shown how the Patient Flow Model provides a wide variety of information to help support the decision-making needs of persons working in hospital settings. One of the notable advantages of the Patient Flow Model is that the model generates a wealth of information within a single application package. This is in contrast to the current practice in most Canadian hospitals where a large amount of financial and operational information is available, but the information comes from multiple application sources.

Almost all Canadian hospitals have now installed powerful, computerized record-keeping systems. These systems usually have a strong clinical focus,[28] although hospitals in all provinces are now required to also have some type of financial reporting in the form of a

[28] The tracking of patients in the hospital, and the care they are receiving using a central patient index is usually one of the primary applications brought on-line.

computerized general ledger reporting system. Provincial health ministries encourage hospitals to install clinical and financial systems that are in conformance with the specifications found in the MIS Guidelines [CIHI, 1997a].

Although the recommended functional specifications for systems are provided as part of a set of national guidelines, hospitals have complete choice in the selection of application vendors when choosing to install computerized systems. The marketplace is well served by over 100 application software vendors who compete for the business of Canadian hospitals [COACH, 1997]. The result is that, in many hospitals, multiple and divergent systems have been installed to best meet the needs of individual users. These systems may be purchased from different vendors, and may even run on different platforms. A small selection of the type of application systems used by hospitals is presented below:

- Core Patient Information Systems
  - Central Patient Index
  - Emergency Patient Information
  - Order Entry
  - Appointment Scheduling
- Patient Care
  - Electronic Charting
  - Care Planning
  - Provider Enquiry
  - Medication Administration
- Human Resources
  - Payroll
  - Automated Time Keeping
- Financial Administration
  - General Ledger
  - MIS G/L Mapping
  - Budget Forecasting
  - Budget Simulation
  - Activity Based Costing

The Patient Flow Model is not designed to be a replacement for these applications. In many cases, the Patient Flow Model provides information that parallels that generated by systems already installed. For example, expenses organised by general ledger expense code are available from both the Patient Flow Model and the hospital's general ledger reporting system. For other applications, the Patient Flow Model generates information that complements that generated by the primary application. For example, the Patient Flow Model provides information that shows labour costs organised by activity performed, whereas payroll systems usually only report labour costs organised by the functional centre where the labour cost was incurred. And lastly, in some cases the Patient Flow Model provides information that is not available from other application systems in the hospital. For example, identifying clinical paths that minimise the use of resources without affecting the number of patients treated is usually not possible using the conventional application systems installed by Canadian hospitals.

The difference between current practice and the integrated application approach offered by the Patient Flow Model can be illustrated by considering three common application portfolios. Each of these application portfolios is currently handled using a different software tool. All three of these functions are incorporated into the Patient Flow Model.[29]

Nursing workload planning is the process by which hospitals examine their patient load profile and make decisions about the quantity and type (e.g., RN, RPN, nursing aide) of nursing assistance required to care for these patients. When performed in a prospective mode, workload

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[29] It is recognised that dedicated application products are designed to address a specific decision-making need. Thus, it is expected that the stand-alone application will provide more complete information for this specific decision-making need than an integrated tool such as the Patient Flow Model.

planning tools allow a hospital to determine the number of nurses to schedule for the upcoming planning period. A common workload planning tool is GRASP® marketed by GRASP Systems International. GRASP® is available in both a manual (i.e., non-computerized) form and as a computerized application tool. In both cases, however, estimates of nursing workload are generated based on characteristics of the patients expected to be cared for during the upcoming planning period. This is somewhat similar to the approach taken by the Patient Flow Model except that the Patient Flow Model is able to easily recalculate the workload expectation based on changes in the clinical paths actually followed by patients. The Patient Flow Model offers an additional advantage over GRASP® in that the model helps identify the specific type and quantity of nursing Resource needed in situations where insufficient Resources are available to handle the expected patient load.

Bed planning and length of stay calculations in Ontario hospitals are supported by a software tool provided by the Ontario Ministry of Health called POST. By modelling beds as a Resource and summing the reported time attributes in Treatment nodes along any particular clinical path, it is also possible to use the Patient Flow Model for bed planning purposes and length of stay calculations. The Patient Flow Model has the added advantage of being able to explore the impact of making changes in the availability of the BED Resource, and/or in reconfiguring the type of BED Resources available. (e.g., Changing BEDS from being available in ward, semi-private or private rooms.) This is not something that can be achieved with the POST tool.

The preparation of budgets to support operating plans (also called business plans in some provinces) is another application that is commonly supported by stand-alone applications within hospitals. Spreadsheets are often used for this purpose. Spreadsheets are ideally suited for presenting financial information and exploring what-if scenarios. The flexible power of the spreadsheet environment was a factor that led to the choice of this tool as a prototyping vehicle for the Patient Flow Model. Because the functional specifications of the Patient Flow Model include data on the availability of Resources, and the implementation of the model provides information on the profile of Treatment activities performed by a hospital, it is also possible to use the Patient Flow Model to generate budgets. The Patient Flow Model has the added advantage of allowing the budget preparer to examine Resource usage from an activity-driven perspective, and when implemented, also allows the budget preparer to explicitly identify the cost of unused capacity in budget documents.

Thus, it is seen that the Patient Flow Model offers users the ability to obtain, in a single package, information that is traditionally obtained from different application software sources. And in each case, the integrated nature of the Patient Flow Model provides the user with additional functionality or information that would not have been available from the stand-alone package. This helps contribute to the utility of the Patient Flow Model as a decision-support aid for managers and care providers working in healthcare settings.

5.6 Summary

This chapter provided an overview of the process by which Patient Flow Models are developed. Important criteria to consider before building a Patient Flow Model was presented. Checklists and guidelines for developing models were also developed. Users who follow this methodology will find they are able to develop comprehensive, clinically-focussed, resource-based data models.

Three demonstration models were then introduced. The vaccination and chest pain models demonstrated the Patient Flow Model's ability to identify clinical pathways that met pre-specified objective functions. The process by which the measurement of Resource use is accomplished was also discussed. The Traumatic Stress Program models demonstrated how the Patient Flow Model is able to capture clinical pathway and resource flow information in more complex environments. The chapter concluded by demonstrating the wide range of financial reports the Patient Flow Model is able to generate.

The following chapter reviews the development and structure of the Patient Flow Model and lays the groundwork for subsequent research.

Chapter 6
Summary & Future Directions

6.0 Introduction

Previous chapters have shown the Patient Flow Model to be an approach to data modelling designed to allow users to explore complex problems of interest to decision-makers working in health care settings. The Patient Flow Model provides decision-makers with an means of problem representation that, when operationalised, allows users to simultaneously examine the interaction that exists between the process of providing healthcare and the resources needed to provide that care.

This chapter summarises the research undertaken to date and comments on future directions for the Patient Flow Model. The topics discussed in this chapter include:

- key features of the Patient Flow Model
- moving from planning to scheduling models
- handling non-value added treatments

- the use of Resources by Treatments outside of the Clinical Network
- allowing Resource Packages to be inventoried
- enhancements to allow the non-linear use of Resources by Treatments
- incorporating revenue recognition
- adding outcome measurement

The chapter concludes by reviewing the motivation that makes the development of a decision-support tool such as the Patient Flow Model so timely.

6.1 Summary - Advantages, Key Features, Contribution

The Patient Flow Model asserts (and this research has shown) that the highly complex and inter-dependent processes involved in providing care for hospital patients can be represented using a network-based model built using only four components. (These components are Activities, Patient States, Resources and Pathways.) Keeping the number of components to a minimum makes it easier for users to quickly grasp the process of building and using Patient Flow Models.

While choosing to employ relatively few components to design models of complex settings is in itself an important feature of the Patient Flow Model, the model's real strength stems from the fact that only one rule is needed to operationalise the model. That rule is that there must be a conservation of flows at each node in the network.

Other notable features of the Patient Flow Model demonstrated in this research include:

- The design of the Patient Flow Model is completely independent of the tool(s) chosen to implement the model.

The Patient Flow Model concept can be implemented using any software application with the required data storage and data manipulation functionality. The structure and conceptual design of the Patient Flow Model remains the same irrespective of the tool used to operationalise the model.

- The Patient Flow Model is both a descriptive and a prescriptive model.

  The *same* Patient Flow Model can be used to explore *what should* happen given a particular patient demand profile, as can be used to examine *what did* happen given a particular patient demand profile.

- The Patient Flow Model has both optimisation and simulation capabilities.

  The Patient Flow Model is specifically designed to support the use of mathematical goal seeking routines. This allows model users to explore optimisation and simulation-based problems.

- Users are free to adopt whatever accounting and reporting conventions best suit their decision-making requirements.

  The method by which cost accumulation information is reported can be defined by the model user. Users are free to select appropriate resource and activity drivers. Unused capacity costs can be explicitly recognised when doing so would provide insights into cost behaviours. Global, departmental dimension, and MIS Chart of Account[1] information can be generated if required. And when desired, full absorption costing can be employed.

These features combine to offer healthcare decision-makers a powerful and flexible clinically-focused, financially-oriented approach to data modelling. In doing so, the Patient Flow Model makes three important contributions.

First, the Patient Flow Model introduces a method for data modelling that is *unique* in its ability to portray the complex interaction between clinical practice and the process by which

[1] Global and departmental dimension reporting are elements of the costing methodology used by Canadian hospitals as defined in CIHI [1996]. The MIS Chart of Accounts is the standardised general ledger coding scheme used by Canadian hospitals. See Chapter 2.

resources are used to provide care. Second, the Patient Flow Model provides hospitals with the specifications for a computerized tool able to support an activity-driven approach to cost determination that can *complement* the conventional two-stage allocation process currently used. And lastly, the Patient Flow Model demonstrates how constructs drawn from the operational, accounting and healthcare literature can be *combined* in an inter-disciplinary manner.

6.2 Ideas for Future Research Endeavours

The development of the Patient Flow Model provided insights into issues to explore as extensions to the model. Many of these extensions will provide additional functionality to the Patient Flow Model. This section reviews these ideas.

6.2.1 Moving from Planning to Scheduling

The version of the Patient Flow Model developed in this research is a single period model. While the model provides insights into events that have or could occur during this single-period horizon, the model is not a multi-period planning tool, nor is the model a scheduling tool.

An intermediate step toward creating multi-period planning capabilities could be achieved using the current Patient Flow Model design by using short time horizons (e.g., hours or shifts) and running successive models to simulate successive planning periods.[2] The output from one firing of the model can be used as the input to the subsequent firing. The shorter the planning period chosen, the closer the Patient Flow Model comes to offering rudimentary scheduling capabilities. A second

[2] Planning horizons used with the Patient Flow Model are usually measured in weeks or months.

option is to export the output from a Patient Flow Model to a scheduling tool where the sequence of tasks is considered. The present form of the Patient Flow Model does not address sequencing issues.

While this research does not address how a plan becomes a schedule, it is asserted that the Patient Flow Model provides a good framework upon which scheduling capabilities can be developed.

6.2.2 Tracing Cost Flows Leaving Treatments

In Section 4.6.2 it was observed that the "value" of every patient leaving a Treatment node is increased by that patient's proportionate share of the Resources used to support the Treatment. Thus, if a Treatment consumes $40,000 in Resources, and 4,000 patients received the Treatment, the Patient Flow Model considers each patient to have "increased" in value by $1,000.

This may not always be the desired outcome for accounting purposes. The case of a high cost diagnostic procedure was discussed. If a hospital wants to determine the cost of operating a specialised program, it may want to ensure that patients with the positive diagnosis bear the complete cost of the program and that program costs are not allocated to patients who are separated because they are found not to share the diagnosis.

This is not what would happen in the existing design of the Patient Flow Model. The $40,000 in Resource costs will be apportioned between the possible exit States based on the number of patients exiting in each exit State. For example, if 75% of patients are found to have the condition diagnosed by the Treatment, $30,000 worth of Resource costs will be associated with these patients.

The remaining $10,000 will follow patients who tested negative. This presents a problem if the hospital would like to see the full $40,000 follow the patients with the positive diagnosis.

A future enhancement is suggested to overcome this situation. When necessary, Clinical Pathways could be marked as *non-value added* pathways. A non-value clinical pathway would accept patient flows based on Treatment Distribution Factors, but the incremental value of the Treatment just received would be recorded as $0.

Another solution that would achieve similar results is to introduce a Cost Distribution Factor parameter to complement Treatment Distribution Factors. The Treatment Distribution Factor explains the relative proportion of patients leaving in each state, and is currently used as a proxy for the relative proportion of costs that should follow each exit arc. Instead of using a proxy for cost distributions, the Cost Distribution Factor would explicitly specify the proportion of *costs* that should follow each exit arc from a Treatment. This approach offers even more flexibility than using non-value added pathways. The implications to the Patient Flow Model of these enhancements is left for further study.

6.2.3 Use of Resources by Treatments Outside the Clinical Network

One of the keys to successful modelling was shown in Chapter 4 to be selecting an area to model that made use of captive Resources. These are Resources that are accessed and used only by Treatments in the area being modelled. While this is the ideal state, it is recognised that there are often times when demands will be placed on Resources by Treatments that lie outside of the associated Clinical Network. The example of an emergency department having the right to borrow nurses in a crisis from the hospital ward being modelled was given.

A few work-arounds were considered as part of this research. The first is to ignore the problem if the demand for the Resource by Treatments outside the Clinical Network is immaterial and/or infrequent. In these cases, model users simply need to monitor the unused quantity of the affected Resources. Maintaining a modest amount of slack in the affected Resources ensures that small amounts of the affected Resources are available for use outside of the Clinical Network captured by the model.

In situations where the demand is predictable or material, two other work-arounds are possible. The first is to reduce the quantities available of the affected Resource before defining the Resources to the Patient Flow Model. This makes the Resources reserved for use outside of the associated Clinical Network "invisible" to the Patient Flow Model. The model will ignore the reserved Resources in all calculations. The downside to making the Resources invisible is that users may forget the Resources exist. An additional complication is that financial information generated by the Patient Flow Model will not reconcile with hospital records. (The value of the invisible Resources will be missing.)

A better alternative may be to create "dummy Treatments" in the Clinical Network. A dummy Treatment would represent demand for a Resource coming from areas outside of the Clinical Network. A dummy Treatment would not have patient inflows or outflows. (This is because the dummy Treatment is not part of the clinical process being modelled.) By setting a value for the dummy Treatment's minimum occurrence parameter ($WMIN_j$), the dummy

Treatment will attract Resources from the Resource Network, even though the treatment is not a part of the Clinical Network.

These ideas on how the problem of adjusting for Resource demands coming from outside the area being modelled have not been fully explored. They offer interesting possibilities for extensions to the Patient Flow Model.

6.2.4 Allowing Non-atomic Resources to Be "In-Stock"

In the existing design of the Patient Flow Model, only Resources (and Patient States) can have an opening balance. Resource Packages are imagined to be assembled after the planning period begins. Thus, while there can be quantities of atomic Resources such as milk, meat and bread available at the beginning of the planning period, it is assumed that MEALS (a resource package) will only be assembled once the activity of PREPARE MEAL occurs.

A simple enhancement to the Patient Flow Model would be to add an opening balance parameter and a closing balance variable to the Package Node definition. This would allow non-atomic Resources to be "in-stock" at the beginning of the planning period. For example, a model could reflect that 200 MEALS have already been cooked.

While this improvement is relatively straight-forward from a design viewpoint, it is left to be explored as a future enhancement because careful consideration must be given to the impact on the model's activity-based reporting system. (Resource Packages that have already been assembled at the beginning of a planning period imply that non-Treatment activities occurred in a previous planning period that were *not* caused by patients passing through Treatments. This is a break from the current paradigm of the Patient Flow Model, but one that might easily be overcome after careful examination.)

6.2.5 Allowing the Non-Linear Use of Resources

The current version of the Patient Flow Model requires Treatments to use Resources in a linear manner. For many Treatments, Resources are consumed in a linear fashion. In fact, the cost accounting methodology used by Canadian hospitals [see CIHI, 1997a; 1995] is based on the premise that there is a linear relationship between the labour output of a hospital unit and the consumption of other resources by that unit.

An interesting extension to the Patient Flow Model would be to enhance the model to permit the non-linear use of Resources by Treatments. As an example, consider data collected to develop Clinical and Resource Networks that shows a technician can treat 6 patients per hour and is paid $30/hr. The existing Patient Flow Model would associate the value of 10 minutes of the technicians time (i.e., $5.00) with each patient receiving the Treatment.

Closer examination, however, shows the technician actually spends 45 minutes with every 6th patient because provincial laws require recalibration of the equipment every hour. So in actual fact, the sixth patient "costs" $22.50 (45min/60min * $30/hr), while the 1st through 5th patient only cost $1.50 each to treat ((60min - 45min)÷5 patients * $30). Assuming that six patients are treated every hour, the difference between the actual cost and the implied (or average) cost of treating patients is immaterial. But potentially misleading information *will* be generated by the Patient Flow Model in situations where the system is not running at capacity. In a situation where there is only one patient each hour, the cost of treating that patient should really be reported as $22.50. The remaining $7.50 should be reported as the technical Resource's cost of unused capacity. The Patient Flow Model, however, will report $5 as the cost of treating the patient, and will incorrectly report the cost of not fully utilizing the Technician Resource as $25.

This problem can be overcome by adding non-linear capabilities to the Patient Flow Model. The design of the Treatment node could be enhanced to allow non-linear Resource consumption. In the Clinical Dimension, Treatments could be modelled to show either the prefixed or suffixed activity(ies) that result(s) in the non-linearity. Solution engines with non-linear capabilities would then be used instead of linear programming engines to determine solutions to Patient Flow Model based problems.

6.2.6 Adding Revenue Recognition

The version of the Patient Flow Model developed in this research focused solely on clinical flows and cost determination. An enhancement to the model to allow revenue streams to be explicitly recognised will be a useful extension to the model for use in some settings.

This might be operationalised by associating a "Fee" parameter with Treatments, or alternatively, by developing a technique to recognize revenue-based Resources. (In the current model, Resources are considered to "cost" money. It would be useful to explore how a Resource such as CASH could be incorporated in Resource Network.)

6.2.7 Adding Outcome Measurement

The optimisation capabilities of the Patient Flow Model could be further exploited by adding parameters for outcome measurement. Outcome measurement is currently of considerable interest in the healthcare field. As one physician said during this study, "Its one thing to know that based on the best diagnosis available, I was able to remove someone's appendix in a cost-effective manner. It's quite another thing to know whether that was the best thing to do."

Outcome measurement is beyond the scope of the Patient Flow Model design outlined in this document. However, as a future extension to the model it would be useful to examine how certain outcome states could be somehow weighted as being more desirable than other states. The functionality of the existing Patient Flow Model could then be used to favour Clinical Paths that result in these "best" outcome states.

An even more advanced application, and one that deserves future study, is to explore the viability of retrospectively populating a Patient Flow Model with data on actual outcomes. If artificial intelligence capabilities were added to the model, it is envisaged that the Patient Flow Model could "learn" from the outcomes of previous scenarios. These "learnings" would be incorporated into the solution engine, and could be used to influence the Clinical Path recommended for subsequent patients who have the same initial diagnosis. The prospect of combining artificial intelligence capabilities with the mathematical modelling techniques used in the Patient Flow Model is rather exciting.

6.3 Conclusion

This research has shown how the Patient Flow Model offers an innovative approach to the modelling of clinical and resource flows in healthcare settings. The Patient Flow Model provides decision-makers with a means of problem representation that, when operationalised, allows users to simultaneously examine the interaction that exists between the process of providing healthcare and the resources needed to provide that care.

In doing so, the Patient Flow Model provides a means to seamlessly integrate the world of clinical practice with the domain of management reporting. And, some 125 years later, contributes to fulfilling Florence Nightingale's call for a way to *"show subscribers how their money was spent, what amount of good was done with it, [and know] whether the money was not doing mischief rather than good."*

Appendix A
Summary of Symbolic Notation Used In the Patient Flow Model

nota-tion	Data Element	Unit of Measurement	Attribute of
A	Acquisition Cost	$	Resource
c	Cost	$	Package, Resource, Treatment
d	Separations	patients	Patient State
E	Opening Balance	patients	Patient State
		resource units	Resource
f	Closing Balance	patient	Patient State
		resource units	Resource
h	Package Name	n/a	Resource Package
i	Patient State Name	n/a	Patient State
j	Treatment Name	n/a	Treatment
k	Resource Name	n/a	Resource
Q	Acquisition Quantity	resource units	Resource
r	Admissions	patients	Patient State
s	Supply	resource units	Resource
w	Occurrences	patients	Treatment
		resource units	Resource
		count	Package
x	Inflow Count	patients	Treatment
y	Outflow Count	patients	Treatment
z	Outflow Count	units	Resource
		units	Package
α	Equivalency Multiplier	relative units	Treatment, Package
β	Treatment Distribution Factor	percent	Treatment
γ	Treatment Acquisition Factor	percent	Treatment
δ	State Distribution Factor	percent	Patient State

Appendix B
Glossary of Terms Used in the Patient Flow Model

aggregation	The grouping of related non-Treatment activities or Resource Packages into a higher level entity. Aggregation occurs only in the Resource Network. See Section 4.5.4. Related Term(s): disaggregation.
Captive Resource	A Resource that is not shared with Treatments outside the domain being modeled.
Chartable Event	See Chartable Treatment.
Chartable Treatment	Any intervention recorded in a patient's medical record. Related Terms: Chartable Event.
Clinical Dimension	That portion of a Patient Flow Model that focusses on data and information regarding the flow of patients through Treatments.
Clinical Flow	The movement of patients along a Clinical Pathway.
Clinical Network	A schematic representation of the Clinical Dimension.
Clinical Pathway	Any arc in a Clinical Network connected to a Patient State Node. Clinical pathways flow along a horizontal axis and are generally drawn so that the default flow direction is from the left to right side of a Patient Flow Model network diagram. Clinical Pathways are shown using solid lines.
Clinical Path	The route followed by a patient through the Clinical Network between the point of admission and the point of separation.

Clinical Protocol	A Clinical Path that follows generally accepted practice standards that for patients with a specific diagnosis. See Section 3.3.2. Related Term(s): Treatment Protocol.
compression	The process of combining Treatments normally modelled individually to create a single "macro" Treatment. Compression is a horizontal abstraction in the Patient Flow Model. See Section 5.1.2, Step 3. Related Term(s): Expansion
Consumable Resource	Any Resource where the quantity on-hand of the Resource is physically depleted each time the Resource is used in an activity. Drugs and bandages are representative examples. See Section 4.5.1.
equivalency multiplier	Explains the cardinality of the relationship between parent and child nodes in the Resource Network. The equivalency multiplier (α) indicates the number of units of a child node required for each occurrence of the parent node. See Section 3.3.4.
expansion	The process of recasting a single Treatment as a series of more specific Treatments. See Section 5.1.2, Step 3. Related Term(s): Compression
intervention	A medically related procedure administered or supervised by a medical practitioner. Examples are administering an injection and clearing an airway. Interventions are one of four Treatment modalities.
non-Treatment activity	An activity that uses Resources but *does not* involve direct patient care. See Section 4.4 and Section 4.5.2.
patient load profile	A description of the number of patients in each Patient State at the beginning of the planning horizon together with the specifications for the number of patients that must be admitted in each Patient State during the planning horizon.
Patient State Node	Used to reflect the condition (or "state") of patients as they progress through a Clinical Path. See Section 3.3.1.
Persistent Resource	A Resource that does not disappear as used. The only difference in the utility of the Resource between the beginning and end of the planning period is an artificial difference in value created for accounting purposes. An MRI Scanner is an example. See Section 4.5.1.
Planned Time Unit	The unit of measurement used to record the expected duration of a Treatment (per patient) based on a health care facility's previous experience. See Section 3.3.2. Related Term(s): Reported Time Unit.

Resource	Supplies, labour and equipment. See Section 3.3.3.
Resource Dimension	Provides data and information regarding the flow of Resources through a healthcare facility. The focus of the Resource Dimension is on the quantity and cost of Resources used during the provision of care. The specifications for the Resource Dimension are reflected in a diagram called the Resource Network.
Resource Flow	The movement of Resources along a Resource Pathway. Can be stated in Resource Units or monetary units.
Resource Pathways	Any arc in a Patient Flow Model network connected to either a Resource and/or a Resource Package Node. Resource pathways follow the vertical axis in a Patient Flow Model network diagram and the default flow direction is from the bottom of the network diagram toward the top. Resource pathways are shown using dashed lines.
Reporting Time Unit	The unit of measurement used to record the time required (per patient) for a Treatment. The default value for Reported Time is the value specified in the Workload Measurement System component of the MIS Guidelines. See Section 3.3.2. Related Term(s): Planned Time Unit.
Secondary Account Codes	Specify expense categories within an MIS Guideline compliant chart of accounts as used by Canadian hospitals.
separation	Term used by health service providers to describe the termination of the care relationship with a patient. Separation can describe being discharged, being transferred to another program or hospital, or movements to the morgue.
State	See Patient State Node.
Treatment	Any activity involving a patient that consumes Resources. See Sections 3.3.2.
Treatment Distribution Factor (β)	The proportion of patients leaving Treatment j in Patient State i.
treatment protocol	See Clinical Protocol.
unused capacity	That portion of a Persistent Resource that was not used to provide care during the planning period, but that must be recognized for accounting purposes as having been used.

Appendix C
Screen Captures from Demonstration Patient Flow Models

Chestpain Demonstration Model — CHEST.XLS SERIES — 13:10

Panel 1 — (adds MIS) Development Prototype CHEST-13.XLS (uses PFM.XLM)

Patient State Nodes (PSN)

Identifier	Constraints on new admissions Min	Max	Actual Admissions (r)	From PHN (Inv) (u)	From Prev Treatmts (Yij)	Separation Constraint Max (dmax)	Suggested Max	Separ'tns (Exiting) (d)	To Next Treatmts (Xij)	To PHN (Inv) (v)	Flow Control (must = 0)
Chestpain			180	0.0	0		0	0	180	0.0	0.0
No Relief			0	0.0	30		180	30	0	0.0	0.0
Relief			0	0.0	150		180	150	0	0.0	0.0
			0	0.0				0	0	0.0	
			0	0.0				0		0.0	
			0	0.0				0		0.0	

Make changes in grey shaded areas only.

Values in red boxes will be calculated by Excel.

Fully functional -

Applies penalty for not being admitted.

State Nodes | HoldingNodes | Treatmt Nodes | Re-sources

View Diagram | Summary Data | Solve Choices

Chestpain Demonstration Model CHEST.XLS SERIES 0 0-Jan-00 13:11

Panel 2 (adds MIS) Development Prototype CHEST-13.XLS 0 0-Jan-00

Patient Holding Nodes (PHN)

Identifier	Opening Balance (H)	From PSN (v)	To PSN (u)	Constraints on Final Holding Levels Min	Max	Sugg Max	Closing Balance (I)	Flow Control (must = 0)
Chestpain	0	0.0	0.0	0	999	180	0	0
No Relief	0	0.0	0.0	0	999	180	0	0
Relief	0	0.0	0.0	0	999	180	0	0

Make changes in grey shaded areas only.

State Nodes | HoldingNodes | Treatmt Nodes | Re-sources

View Diagram | Summary Data | Solve Choices

Chestpain Demonstration Model CHEST.XLS SERIES 0 1/0/00 13:11

Panel 3 (adds MIS) Development Prototype CHEST-13.XLS 0 1/0/00

Treatments - Inflow Rates

From PSN	To Treatment	Xij
Chestpain	Admin Drug	100.000
Chestpain	Bedrest	80
		0

Treatments - Outflow Rates

From Treatment	To PSN	Outflows %	rhs	Yij
Admin Drug	No Relief	0.1	10	10.000
Admin Drug	Relief	0.9	90	90.000
Bedrest	Relief	0.75	60	60
Bedrest	No Relief	0.25	20	20
				0

Make changes in grey shaded areas only.
Values in red boxes will be calculated by Excel.

State Nodes | HoldingNodes | Treatmt Nodes | Re-sources
View Diagram | Summary Data | Solve Choices

Chestpain Demonstration Model — CHEST.XLS SERIES

Panel 4 — (adds MIS) Development Prototype CHEST-13.XLS

Treatment Nodes - Details on Capacity & Utilization

Treatment Identifier	Constraints on Treatmt Thruput Min	Max	Cost to Perform $	Patients Entering Treatmt	Patients Leaving Treatmt	Tot Cost of Performing Treatmt	Time Units Rqd to Perform	Total Time Units Consumed
Admin Drug	0	9999	$3,030	100	100	$303,000	1	100
Bedrest	0	9999	$1,650	80	80	$132,000	72	5760

Make changes in grey shaded areas only.

State Nodes | HoldingNodes | Treatmt Nodes | Re-sources

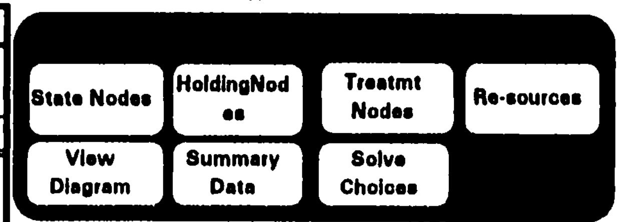
View Diagram | Summary Data | Solve Choices

Inflows/ Outflows

Chestpain Demonstration Model — **CHEST.XLS SERIES**

Panel 5 — (adds MIS) Development Prototype CHEST-13.XLS

Model Summary (1)	
Total Patients Admitted During Period	180
Patients in Holding at Beginning of Period	0
	180
Total Patient Separations	180
Patients Left in Holding at End of Period	0
	180
Resource Consumption/Financial Report	
Nursing Care (actually used)	$15,000
Drug Costs	$300,000
Ward care	$120,000
Value of Resources Paid For but Not Used	$3,000
Total Cost of Providing Care	$438,000
Average Cost per Separation	$2,433
Average Length of Stay (days)	1.36



Resource Notes:
Nurse hrs are still avbl.
Drugs used to limit
Ward care is available.

Chestpain Demonstration Model CHEST.XLS SERIES Se

Panel 5a (adds MIS) Development Prototype CHEST-13.XLS

To see what happens if the goal is to minimize the patient's length of stay, click here... [Solve! Minimize LOS]

To see what happens if the goal is to help as many patients as possible experience relief from chestpain, click here... [Solve! Best Outcome]

To see what happens if the goal is to minimize total costs, click here... [Solve! Minimize Costs]

Move Next To:

State Nodes	HoldingNodes	Treatmt Nodes	Re-sources
View Diagram	Summary Data	Solve Choices	

clear cells disabled

Docum'tn | Clear Dec. Cells!

Panel 5b   Misc Calculations   (adds MIS) Development Prototype CHEST-13.XLS

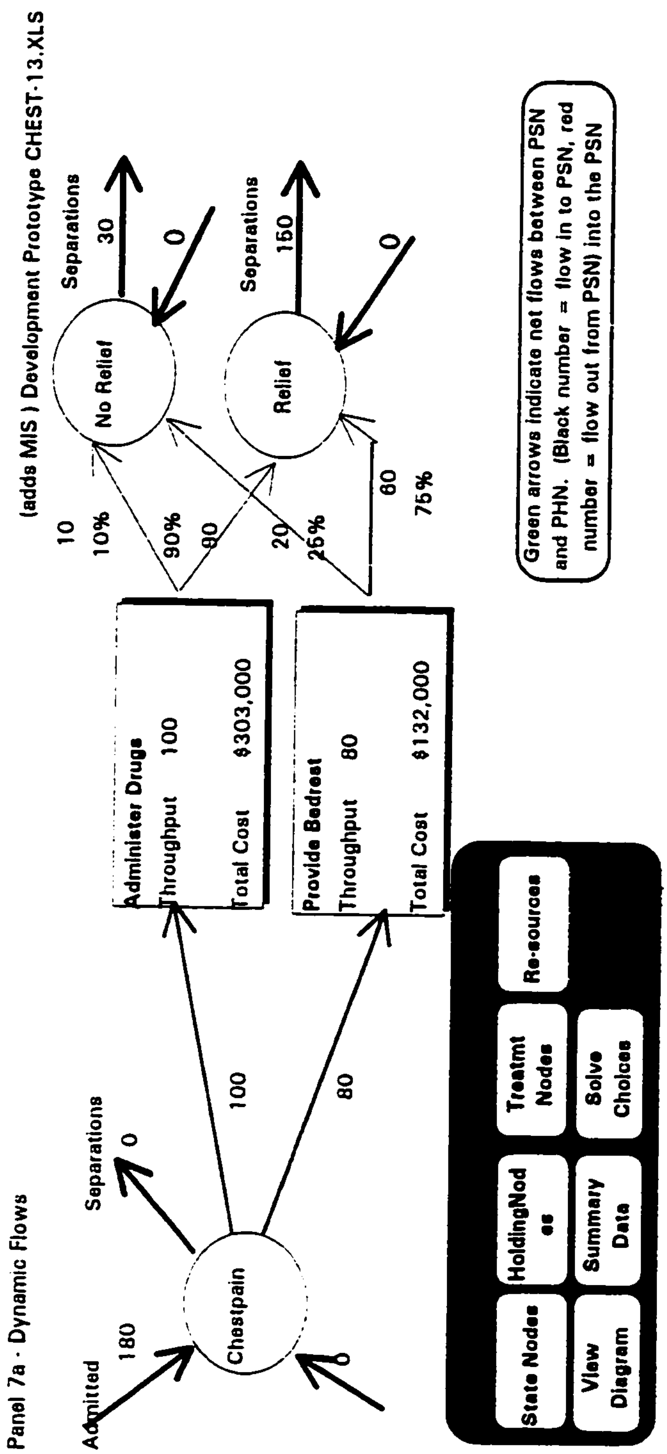
Return

Determining max patient load expected:		
Max possible admissions (sum of max r)		180
Patients already admitted (sum of H's)		0
Max Patient Load Possible	(Max_Load)	180

PHN Sumry	Chestpain	NoRelief	Relief
(open) H	0	0	0
(in) v	0	0	0
(out) u	0	0	0
(close) f	0	0	0

Phantom Values to Encourage Separations (added in CHEST-5.XLS)			weight	extension
Total Patient Separations		180		
Total Desired Separations (relief)		150	1000	150000
Total Less Desirable Separations		30	0.01	0.3
Patients Not Admitted		0	-0.01	0
Plugged Value of a Separation	$500,000	All Outcomes		150000.3 <- max this to maximize relief s
Total "value" of separations		$90,000,000		
Cost of Treatments Provided		$300,000		
Max this amt to solve for min cost of treatment		$89,700,000		
Plugged time weight per separation	1000			
Potential LOS for patients separated		180000		
Actual time units consumed		5860		
Maximize this difference		174140		

Cost per separation	Occurences	Cost	Extention
Admin Drugs	100.000	$3,030	$303,000
Bedrest	80	$1,650	$132,000
Add Unused Capacity Costs			$3,000
Total Period Costs			$438,000
Separations			$180
Avg Cost Per Separation			$2,433



Panel 7a - Dynamic Flows
(adds MIS) Development Prototype CHEST-13.XLS
Admitted
180
Separations
0
Chestpain
0
100
80
Administer Drugs
Throughput 100
Total Cost $303,000
Provide Bedrest
Throughput 80
Total Cost $132,000
10
10%
90%
80
20
25%
60
75%
No Relief
Separations
30
0
Relief
Separations
150
0
Green arrows indicate net flows between PSN and PHN. (Black number = flow in to PSN, red number = flow out from PSN) into the PSN
State Nodes
HoldingNodes
Treatmt Nodes
Re-sources
View Diagram
Summary Data
Solve Choices

Chestpain Demonstration Model — CHEST.XLS SERIES — 0 — 0-Jan-00 13:11

Panel 8 — (adds MIS) Development Prototype CHEST-13.XLS — 0 — 0-Jan-00

Resources

Resource	Unit of Measure	Unit Cost	Persis or Consumbl	Units Avbl	Equivalency Multipliers Admin Drug	Bedrest
Nurse	hr	$30.00	P	600	1.0	6.0
Drug	dose	$2,000.00	C	100	1.0	0.0
Wardcare	bedday	$500.00	C	330	0.0	3.0

State Nodes | HoldingNodes | View Diagram | Summary Data | Treatmt Nodes | Solve Choices

Resource Consumption

Treatment	Occurences	Resources Quantities Used Nurse	Drug	Wardcare	Resource Costs Incurred Nurse	Drug	Wardcare	Tot Treatmt Cost	Per Patient
Admin Drug	100	100	100.0	0	$3,000	$300,000	$0	$303,000	$3,030
Bedrest	80	400	0	240	$12,000	$0	$120,000	$132,000	$1,650
	Required:	500	100	240					
	Available:	600	100	330					
	% consumed:	83%	100%	73%					
				$ Value of Resources Used:	$15,000	$300,000	$120,000		
				Persistent Resource?	Yes	No	No		
				Cost of Unused Capacity	$3,000	not applic.	not applic.		
				Total Unused Capacity Costs		$3,000			

Chestpain Demonstration Model — **CHEST.XLS SERIES** — 0 0-Jan-00 13:11

Panel 9 — (adds MIS) Development Prototype CHEST-13.XLS — 0 0-Jan-00

Model Summary (2)				
Treatment				
Administer Drug	Patients Treated: 100 at $3030 each.			
Nursing Care (actually used)		100 hrs	$3,000	
Drug Costs		100 doses	$300,000	
Total Cost of Drug Treatment				$303,000
Bedrest	Patients Treated: 80 at $1650 each.			
Nursing Care (actually used)		400 hrs	$12,000	
Ward care		240 beddays	$120,000	
Total cost of Bedrest Treatment				$132,000
Value of Resources Paid for but Not Used				
Nursing		100 hrs	$3,000	
Total value of resources paid for but not used				$3,000
Total Cost of Providing Care				$438,000
Average Cost per Separation				$2,433
Average Length of Stay (days)				1.36

Objective function was last set to
Maximize Best Outcomes

Resource Notes: Nurse hrs are still avbl. Drugs used to limit Ward care is available.

State Nodes | **Re-sources** | **View Diagram**
HoldingNodes | **Summary Data**
Treatmt Nodes | **Solve Choices**

Panel 1 - Patient States			Inflow Management					Outflow Management - d(i)					Holding Management				Flow Control
				Limits on New Admissions			From	Limits on Separations				Leaving	Limits on Final Holding				
Identifier i	Patient State	Day	OpenBal E(i)	RMIN(i)	RMAX(i)	Actual Admis'ns r(i)	Previous Events sum y(i)	DMIN(i)	DMAX(i)	col not needed	Actual Separ'ns d(i)	for Next Events sum x(i)	Min FMIN(i)	Max FMAX(i)	col not needed	Ending Balance f(i)	low Must =0
Sw_1	Starting a new week	Sw_1	25	5	5	5.00	0.00	0	0		0.00	30.00	0	0		0.00	0.00
Sw_2	Referred to Mind/Body w/G&D	Sw_2	0	0	0	0.00	8.50	0	0		0.00	8.50	0	0		0.00	0.00
Sw_3	Process Group 1 Member	Sw_3	0	0	0	0.00	8.25	0	0		0.00	8.25	0	0		0.00	0.00
Sw_4	Process Group 2 Member	Sw_4	0	0	0	0.00	8.25	0	0		0.00	8.25	0	0		0.00	0.00
Sw_5	Process Group 3 Member	Sw_5	0	0	0	0.00	8.50	0	0		0.00	8.50	0	0		0.00	0.00
Sw_6	Need Mind/Body w/S&C	Sw_6	0	0	0	0.00	8.25	0	0		0.00	8.25	0	0		0.00	0.00
Sw_7	Newly Admitted	Sw_7	0	0	0	0.00	5.00	0	0		0.00	5.00	0	0		0.00	0.00
Sw_8	Hungry for Lunch (Wed)	Sw_8	0	0	0	0.00	30.00	0	0		0.00	30.00	0	0		0.00	0.00
Sw_9	Ready for Hort Therapy	Sw_9	0	0	0	0.00	0.00	0	0		0.00	0.00	0	0		0.00	0.00
Sw_10	Referred to Mind/Body W&M	Sw_10	0	0	0	0.00	1.50	0	0		0.00	1.50	0	0		0.00	0.00
Sw_11	Ready to Explore Spirituality	Sw_11	0	0	0	0.00	14.58	0	0		0.00	14.67	0	0		0.00	0.00
Sw_12	Ready for Dinner	Sw_12	0	0	0	0.00	30.00	0	0		0.00	30.00	0	0		0.00	0.00
Sw_13	Require Psychiatric Assmt	Sw_13	0	0	0	0.00	5.00	0	0		0.00	5.00	0	0		0.00	0.00
Sw_14	Require PNT Assmt	Sw_14	0	0	0	0.00	5.00	0	0		0.00	5.00	0	0		0.00	0.00
Sw_16	Referred to Coping w/Anger	Sw_16	0	0	0	0.00	0.00	0	0		0.00	0.00	0	0		0.00	0.00
Sw_17	Ready for Afternoon	Sw_17	0	0	0	0.00	25.50	0	0		0.00	25.50	0	0		0.00	0.00
Sw_22	Interested in Volleyball	Sw_22	0	0	0	0.00		0	0		0.00		0	0		0.00	0.00
Sw_23	Interested in Chapel	Sw_23	0	0	0	0.00		0	0		0.00		0	0		0.00	0.00
Sw_24	Tired (Wed)	Sw_24	0	0	0	0.00		0	0		0.00		0	0		0.00	0.00
Sw_25	Hungry for Breakfast (Thur)	Sw_25	0	0	0	0.00		0	0		0.00		0	0		0.00	0.00

Panel 2: Clinical Pathways X(i) - Patients Leaving P(i)s
(allowable links appear in red squares - all x(i) values are determined by model)

	From Patient State	To n_meal	To n_admt	To n_gd_mnd	To n_sc_proc	To n_hit	To n_gd_proc	To n_mv_proc	To n_sc_mnd	To n_lunch	To n_anger	To n_wm_mnd	To n_hort	To n_spirit	To n_chert	To n_mealar	To n_mealprt	To n_dinner					Sum Leaving x(i)
Sw_1	Starting a new week	26.00	6.00																				30
Sw_2	Referred to Mind/Body w/G&D			8.50																			8.6
Sw_3	Process Group 1 Member							8.25															8.25
Sw_4	Process Group 2 Member				8.25																		8.25
Sw_5	Process Group 3 Member						8.50																8.6
Sw_6	Need Mind/Body w/S&C								8.25														8.25
Sw_7	Newly Admitted					6.00																	6
Sw_8	Hungry for Lunch (Wed)									30.00													30
Sw_9	Ready for Hort Therapy												0.00										0
Sw_10	Referred to Mind/Body W&M											1.50											1.5
Sw_11	Ready to Explore Spirituality													14.57									14.675
Sw_12	Ready for Dinner																	30.00					30
Sw_13	Require Psychiatric Assmt															6.00							6
Sw_14	Require PNT Assmt																6.00						6
Sw_16	Referred to Coping w/Anger										0.00												0
Sw_17	Ready for Afternoon Tx										0.00		20.60		6.00								26.6
	Total Inflows from Previous States	26.00	6.00	8.50	8.25	6.00	8.50	8.25	8.25	30.00	0.00	1.50	20.60	14.67	6.00	6.00	6.00	30.00	0.00	0.00	0.00	0.00	188.33

Panel 3: y(ij) Clinical Pathways (Patients Emerging From Treatments) - define betas here												
				To Sw_1		To Sw_2		To Sw_3		To Sw_4		To S
		Limits on Tx's		Startng new wk		Rfd GD Mind		Proc Grp 1 Mbr		Proc Grp 2 Mbr		Proc Gr
w(i)	From Treatment	WMINj	WMAXj	beta	y(ij)	beta	y(ij)	beta	y(ij)	beta	y(ij)	beta
[illegible]	Tuesday Hotelling (t_hotel)			[illegible]	0							
25.00	Wed Community Mtg (w_meet)					[illegible]	8.5	[illegible]	8.25	[illegible]	8.25	
8.50	Mind/Body Connect (w_gd_mind)											[illegible]
8.25	Process Group S&C (w_sc_proc)											
5.00	New Admissions Signin (w_admit)	5.00	5.00									
5.00	Tour & Fire (w_hist)											
8.50	Process Grp (G&D) (w_gd_proc)											
8.25	Process Grp (M&W) (w_mw_proc)											
8.25	Mind/Body (S&C) (w_sc_mind)											
30.00	Lunch (w_lunch)											
0.00	Coping w/Anger (w_anger)											
1.50	Mind/Body (w_wm_mind)											
20.50	Hort Therapy (w_hort)											
14.57	Explore Spirituality (w_spirit)											
5.00	Orientation (w_orient)	5.00	5.00									
5.00	Meet Psych (w_meetdr)											
5.00	Meet PNT (w_meetpnt)											
	Total Inflows from Prev Tx (sum y(ij))				0.00		8.50		8.25		8.25	

Panel 3: y(ij) Clinical Pathways (Patients Em

		w_5	To Sw_6		To Sw_7		To Sw_8		To Sw_9		To Sw_10	
		o 3 Mbr	Need S&C Mind		Newly Admitted		Hungry for Lunch		Rdy for Hort		Refd to Mind/Bdy	
w(j)	From Treatment	y(ij)	beta	y(ij)	beta	y(ij)	beta	y(ij)	beta	y(ij)	beta	y(ij)
[illegible]	Tuesday Hotelling (t_hotel)											
25.00	Wed Community Mtg (w_meet)											
8.50	Mind/Body Connect (w_gd_mind)	8.5										
8.25	Process Group S&C (w_sc_proc)		1.0	8.25								
5.00	New Admissions Signin (w_admit)				1.00	5						
5.00	Tour & Fire (w_hist)						1.00	5.00				
8.50	Process Grp (G&D) (w_gd_proc)						1.00	8.50				
8.25	Process Grp (M&W) (w_mw_proc)						1.00	8.25				
8.25	Mind/Body (S&C) (w_sc_mind)						[illegible]	8.25				
30.00	Lunch (w_lunch)										0.05	1.50
0.00	Coping w/Anger (w_anger)										[illegible]	0.00
1.50	Mind/Body (w_wm_mind)											
20.50	Hort Therapy (w_hort)											
14.57	Explore Spirituality (w_spirit)											
5.00	Orientation (w_orient)											
5.00	Meet Psych (w_meetdr)											
5.00	Meet PNT (w_meetpnt)											
	Total Inflows from Prev Tx (sum y(ij))	8.50		8.25		5.00		30.00		0.00		1.50

Panel 3: y(ij) Clinical Pathways (Patients Em													
		To Sw_11		To Sw_12		To Sw_13		To Sw_14		To Sw_16		To Sw_17	
		Rdy to Exp Spirit		Rdy for Dinner		Rqr Psychiatrist		Rqr PNT Asmt		Rfd to Coping		Rdy for PM	
w(i)	From Treatment	beta	y(ij)	beta	y(ij)	beta	y(ij)	beta	y(ij)	beta	y(ij)	beta	y(ij)
[illegible]	Tuesday Hotelling (t_hotel)												
25.00	Wed Community Mtg (w_meet)												
8.50	Mind/Body Connect (w_gd_mind)												
8.25	Process Group S&C (w_sc_proc)												
5.00	New Admissions Signin (w_admit)												
5.00	Tour & Fire (w_hist)												
8.50	Process Grp (G&D) (w_gd_proc)												
8.25	Process Grp (M&W) (w_mw_proc)												
8.25	Mind/Body (S&C) (w_sc_mind)												
30.00	Lunch (w_lunch)			[illegible]	3.00							[illegible]	25.5
0.00	Coping w/Anger (w_anger)	[illegible]	0.00	[illegible]	0.00								
1.50	Mind/Body (w_wm_mind)	[illegible]	0.23	[illegible]	1.28								
20.50	Hort Therapy (w_hort)	[illegible]	14.35	[illegible]	6.15								
14.57	Explore Spirituality (w_spirit)			[illegible]	14.57								
5.00	Orientation (w_orient)					[illegible]	5.00						
5.00	Meet Psych (w_meetdr)							[illegible]	5.00				
5.00	Meet PNT (w_meetpnt)			[illegible]	5.00								
	Total Inflows from Prev Tx (sum y(ij))		14.58		30.00		5.00		5.00		0.00		25.50

Panel 4: Demand for Resource Packages & Resources

		Unit	Meals		$ 4.57	Meds		$ 14.25	AsmtReview		$ 675.00	ChartRevi
w(j)		Cost	alpha	w(h)	$	alpha	w(h)	$	alpha	w(h)	$	alpha
30.00	Lunch (w_lunch)	4.57	1	30	137.00		0	0		0	0	
0.00	Coping w/Anger (w_anger)	147.00		0	0	1	0	0.00		0	0	1
1.50	Mind/Body (W&M) (w_wm_mind)	61.50		0	0		0	0		0	0	1
20.50	Hort Therapy (w_hort)	131.50		0	0		0	0		0	0	1
14.57	Explore Spirituality (w_spirit)	25.50		0	0		0	0		0	0	2
5.00	Orientation (w_orient)	810.00		0	0		0	0	1	5	3375.00	
5.00	Meet Psych (w_meetdr)	67.50		0	0		0	0		0	0	
5.00	New Admissions Signin (w_admit)	99.00		0	0		0	0		0	0	1
5.00	Tour & Fire (w_hist)	15.00		0	0		0	0		0	0	
25.00	Wed Community Mtg (w_meet)	30.00		0	0		0	0		0	0	
8.50	Mind/Body Connect (w_gd_mind)	142.50		0	0		0	0		0	0	
8.50	Process Grp (G&D) (w_gd_proc)	75.00		0	0		0	0		0	0	
8.25	Process Grp (M&W) (w_mw_proc)	75.00		0	0		0	0		0	0	
8.25	Process Grp (S&C) (w_sc_proc)	76.50		0	0		0	0		0	0	1
8.25	Mind/Body (w_sc_mind)	1.50		0	0		0	0		0	0	1
5.00	Meet PNT (w_meetpnt)	15.00		0	0		0	0		0	0	
1.00	*Medical Records (facilty sust'ng)*	330.00		0	0		0	0		0	0	
1.00	*In-service Training (prog sust'ng)*	540.00		0	0		0	0		0	0	
1.00	*Research (prog sust'ng)*	300.00		0	0		0	0		0	0	
	Occurrence & Overall Cost Info:			30	$ 137		0	$ -		5	$ 3,375	
	Test Cells used for min/max trials:				$ 13,360							

Panel 4: Demand for Resource Packages & R

		w	$ 1.50	Admission		97.50	Psychiatrist		$67.50	Therapist		$ 30
w(j)		w(h)	$	alpha	w(h)	$	alpha	w(h)	$	alpha	w(h)	$
30.00	Lunch (w_lunch)	0.0	0.00		0	0		0	0.00		0.0	0.00
0.00	Coping w/Anger (w_anger)	0.0	0.00		0	0		0	0.00	1	0.0	0.00
1.50	Mind/Body (W&M) (w_wm_mind)	1.5	2.25		0	0		0	0.00	2	3.0	90.00
20.50	Hort Therapy (w_hort)	20.5	30.75		0	0		0	0.00	1	20.5	615.00
14.57	Explore Spirituality (w_spirit)	29.1	43.73		0	0		0	0.00		0.0	0.00
5.00	Orientation (w_orient)	0.0	0.00	1	5	487.50		0	0.00	1	5.0	150.00
5.00	Meet Psych (w_meetdr)	0.0	0.00		0	0	1	5	337.50		0.0	0.00
5.00	New Admissions Signin (w_admit)	5.0	7.50	1	5.00	487.50		0	0.00		0.0	0.00
5.00	Tour & Fire (w_hist)	0.0	0.00		0	0		0	0.00		0.0	0.00
25.00	Wed Community Mtg (w_meet)	0.0	0.00		0	0		0	0.00	1	25.0	750.00
8.50	Mind/Body Connect (w_gd_mind)	0.0	0.00		0	0	1	8.50	573.75	1	8.5	255.00
8.50	Process Grp (G&D) (w_gd_proc)	0.0	0.00		0	0		0	0.00	1	8.5	255.00
8.25	Process Grp (M&W) (w_mw_proc)	0.0	0.00		0	0		0	0.00	1	8.2	247.50
8.25	Process Grp (S&C) (w_sc_proc)	8.2	12.38		0	0		0	0.00	1	8.2	247.50
8.25	Mind/Body (w_sc_mind)	8.2	12.38		0	0		0	0.00		0.0	0.00
5.00	Meet PNT (w_meetpnt)	0.0	0.00		0	0		0	0.00		0.0	0.00
1.00	*Medical Records (facilty sust'ng)*	0.0	0.00		0	0	4	4	270.00		0.0	0.00
1.00	*In-service Training (prog sust'ng)*	0.0	0.00		0	0	4	4	270.00	4	4.0	120.00
1.00	*Research (prog sust'ng)*	0.0	0.00		0	0	2	2	135.00	2	2.0	60.00
	Occurrence & Overall Cost Info:	72.65	$ 109		10	$ 975		23.5	$ 1,586		93	$ 2,790
	Test Cells used for min/max trials:											

Panel 4: Demand for Resource Packages & F		PNT		$15	Chaplain		$22.50	Drugs		$1	Supplies		$100
w(i)		alpha	w(h)	$	alpha	w(h)	$	alpha	w(h)	$	alpha	w(h)	$
30.00	Lunch (w_lunch)		0.0	0.00		0	0		0	0		0	0
0.00	Coping w/Anger (w_anger)		0.0	0.00		0	0	1	0	0	1	0	0
1.50	Mind/Body (W&M) (w_wm_mind)		0.0	0.00		0	0		0	0		0	0
20.50	Hort Therapy (w_hort)		0.0	0.00		0	0		0	0	1	20.5	2050
14.57	Explore Spirituality (w_spirit)		0.0	0.00	1	14.6	327.94		0	0		0	0
5.00	Orientation (w_orient)	0.5	2.5	37.50		0	0		0	0		0	0
5.00	Meet Psych (w_meetdr)		0.0	0.00		0	0		0	0		0	0
5.00	New Admissions Signin (w_admit)		0.0	0.00		0	0		0	0		0	0
5.00	Tour & Fire (w_hist)	1	5.0	75.00		0	0		0	0		0	0
25.00	Wed Community Mtg (w_meet)		0.0	0.00		0	0		0	0		0	0
8.50	Mind/Body Connect (w_gd_mind)	3	25.5	382.50		0	0		0	0		0	0
8.50	Process Grp (G&D) (w_gd_proc)	3	25.5	382.50		0	0		0	0		0	0
8.25	Process Grp (M&W) (w_mw_proc)	3	24.8	371.25		0	0		0	0		0	0
8.25	Process Grp (S&C) (w_sc_proc)	3	24.8	371.25		0	0		0	0		0	0
8.25	Mind/Body (w_sc_mind)		0.0	0.00		0	0		0	0		0	0
5.00	Meet PNT (w_meetpnt)	1	5.0	75.00		0	0		0	0		0	0
1.00	*Medical Records (facility sust'ng)*	4	4.0	60.00		0	0		0	0		0	0
1.00	*In-service Training (prog sust'ng)*	4	4.0	60.00	4	4	90		0	0		0	0
1.00	*Research (prog sust'ng)*	4	4.0	60.00	2	2	45		0	0		0	0
	Occurrence & Overall Cost Info:		12.5	$ 1,875		20.575	$ 463		0	$ -		20.5	$ 2,050
	Test Cells used for min/max trials:												

Panel 4: Demand for Resource Packages & F				
w(i)			Duration t(i)	Total Time
30.00	Lunch (w_lunch)		1.0	30.0
0.00	Coping w/Anger (w_anger)		1.0	0.0
1.50	Mind/Body (W&M) (w_wm_mind)		1.5	2.3
20.50	Hort Therapy (w_hort)		1.5	30.7
14.57	Explore Spirituality (w_spirit)		1.0	14.6
5.00	Orientation (w_orient)		1.5	7.5
5.00	Meet Psych (w_meetdr)		1.5	7.5
5.00	New Admissions Signin (w_admit)		1.5	7.5
5.00	Tour & Fire (w_hist)		0.8	3.7
25.00	Wed Community Mtg (w_meet)		0.5	12.5
8.50	Mind/Body Connect (w_gd_mind)		1.0	8.5
8.50	Process Grp (G&D) (w_gd_proc)		1.3	11.3
8.25	Process Grp (M&W) (w_mw_proc)		1.3	11.0
8.25	Process Grp (S&C) (w_sc_proc)		1.3	11.0
8.25	Mind/Body (w_sc_mind)		1.0	8.2
5.00	Meet PNT (w_meetpnt)		1.5	7.5
1.00	*Medical Records (facility sust'ng)*			0.0
1.00	*In-service Training (prog sust'ng)*			0.0
1.00	*Research (prog sust'ng)*			0.0
	Occurrence & Overall Cost Info			
	Test Cells used for min/max trials		TestTime	173.825

Traumatic Stress Models
Panel 6: Measuring Use & Cost for Resources

		Unit	Meat		$ 2.00	Bakery		$ 3.33	Dietician		$ 25.00	Psychiatri
w(k)	Resource Package (Activity)	Cost	z	w(k)	Cost	z	w(k)	Cost	z	w(k)	Cost	z
	Used Directly by Treatments			0	$ -		0	$ -		0	$ -	
30.00	Meals	4.57	0.2	6.00	12	0.50	15	50.00	0.1	3	$ 75	
0.00	Meds	14.25		0.00	0		0	0.00				0 1
5.00	Assmt Review	675.00		0.00	0		0	0.00				6
72.65	Chart Review nb c113 cal'c diffnly	1.50		0.00	0		0	0.00				
10.00	Admission	97.50		0.00	0		0	0.00				1
	Units Demanded & Total Cost			6	$12		15	$50		3	$75	

Traumatic Stress Models
Panel 6: Measuring Use & Cost for Resourc

		st	$ 67.50	Therapist		$ 30.00	PNT		$ 15.00	Chaplain		$ 22.50
w(k)	Resource Package (Activity)	w(k)	Cost	z	w(k)	Cost	z	w(k)	Cost	z	w(k)	Cost
	Used Directly by Treatments	23.5	$ 1,588		93.0	$ 2,790		125	$1,875		20.6	$463
30.00	Meals	0.0	$ -		0.0	$ -		0	$0			
0.00	Meds	0.0	$ -	0.00	0.0	$ -	0.50	0	$0			
5.00	Assmt Review	30.0	$ 2,025	6.00	30.0	$ 900	6.00	30	$450			
72.65	Chart Review nb c113 cal'c diffnly	0.0	$ -	0.10	0.0	$ 0	0.10	7.265	$109			
10.00	Admission	10.0	$ 675	1	10.0	$ 300	0	0	$0			
	Units Demanded & Total Cost	63.5	$4,266		133	$3,990		162.265	$2,434		21	463

Traumatic Stress Models
Panel 6: Measuring Use & Cost for Resourc

		Drugs		$ 1.25	Supplies		$ 100.00
w(k)	Resource Package (Activity)	z	w(k)	Cost	z	w(k)	Cost
	Used Directly by Treatments		0	$ -		20	$ 2,050
30.00	Meals						
0.00	Meds						
5.00	Assmt Review						
72.65	Chart Review nb c113 cal'c diffnly						
10.00	Admission						
	Units Demanded & Total Cost		0	0		20	2050

Panel 6: Resource Nodes (details of amounts purchased and used)
Traumatic Stress Demonstration Models

MIS Code	Resource	Unit of Measure	Resource Behaviour	Resource Type	[illegible]	[illegible]	[illegible]	Unit Cost	[illegible]	Must Buy in Units	[illegible]	Max Buy in Units
R_45010	Meat, Fish, Poultry	kg	C	Patient	[illegible]	[illegible]	[illegible]	$ 2.00	[illegible]	0	[illegible]	5000
R_45040	Bakery Products	loaf	C	Patient	[illegible]	[illegible]	[illegible]	$ 3.33	[illegible]	0	[illegible]	3000
R_RD_350	Dieticians	hr	P	Patient	[illegible]	[illegible]	[illegible]	$ 25.00	[illegible]	0	[illegible]	4000
R_PSY_35	Psychiatrists	hr	P	Program	[illegible]	[illegible]	[illegible]	$ 67.50	[illegible]	0	[illegible]	4000
R_THP_35	Therapists	hr	P	Program	[illegible]	[illegible]	[illegible]	$ 30.00	[illegible]	0	[illegible]	4000
R_PNT_35	PNT (Prime Nurse Therapists)	hr	P	Program	[illegible]	[illegible]	[illegible]	$ 15.00	[illegible]	0	[illegible]	4000
R_CHA_35	Chaplain	hr	P	Program	[illegible]	[illegible]	[illegible]	$ 22.50	[illegible]	0	[illegible]	4000
R_46550	Drugs	dose	C	Patient	[illegible]	[illegible]	[illegible]	$ 1.25	[illegible]	0	[illegible]	4000
R_49510	Supplies - General	case	C	Patient	[illegible]	[illegible]	[illegible]	$ 100.00	[illegible]	0	[illegible]	100

Panel 6: Resource Nodes (details of amount
Traumatic Stress Demonstration Models

MIS Code	Resource	Units Needed (solved)	Min CloseBal FMIN(k)	Max CloseBal FMAX(k)	Unadj'td CloseBal f(k)	Units Used	Flow Control (must=0)	Units That Must Be Bought	Cost of Resource Used	Amount Spent on Resource	Cost of Unused Capacity	Actual Close Bal f(k)
R_45010	Meat, Fish, Poultry	0.0	0	999	44.0	6.0	0.00	0	$ 12	$ -	$ -	44.0
R_45040	Bakery Products	15.0	0	999	0.0	15.0	0.00	30	$ 50	$ 100	$ -	15.0
R_RD_350	Dieticians	3.0	0	999	0.0	3.0	0.00	40	$ 75	$ 1,000	$ 925	not applic
R_PSY_35	Psychiatrists	63.5	0	999	0.0	63.5	0.00	80	$ 4,286	$ 5,400	$ 1,114	not applic
R_THP_35	Therapists	133.0	0	999	0.0	133.0	0.00	160	$ 3,990	$ 4,800	$ 810	not applic
R_PNT_35	PNT (Prime Nurse Therapists)	162.3	0	999	0.0	162.3	0.00	200	$ 2,434	$ 3,000	$ 566	not applic
R_CHA_35	Chaplain	20.6	0	999	0.0	20.6	0.00	40	$ 463	$ 900	$ 437	not applic
R_46550	Drugs	0.0	0	999	0.0	0.0	0.00	0	$ -	$ -	$ -	0.0
R_49510	Supplies - General	20.5	0	999	0.0	20.5	0.00	21	$ 2,050	$ 2,100	$ -	0.5
								571	$ 13,360	$ 17,300	$ 3,852	

Panel 6: Resource Nodes (details of amount
Traumatic Stress Demonstration Models

MIS Code	Resource	Value of Inventory	Classifying Unused Capacity Costs: Patient Sustaining	Encounter Sustaining	Program Sustaining	Facility Sustaining
R_45010	Meat, Fish, Poultry	$ 88	0.0	0.0	0.0	0.0
R_45040	Bakery Products	$ 50	0.0	0.0	0.0	0.0
R_RD_350	Dieticians	not applic	925.0	0.0	0.0	0.0
R_PSY_35	Psychiatrists	not applic	0.0	0.0	1113.8	0.0
R_THP_35	Therapists	not applic	0.0	0.0	810.0	0.0
R_PNT_35	PNT (Prime Nurse Therapists)	not applic	0.0	0.0	566.0	0.0
R_CHA_35	Chaplain	not applic	0.0	0.0	437.1	0.0
R_46550	Drugs	$ -	0.0	0.0	0.0	0.0
R_49510	Supplies - General	$ 50	0.0	0.0	0.0	0.0
		$ 188	$ 925	$ -	$ 2,927	$ -

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IMAGE EVALUATION TEST TARGET (QA-3)

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6"

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