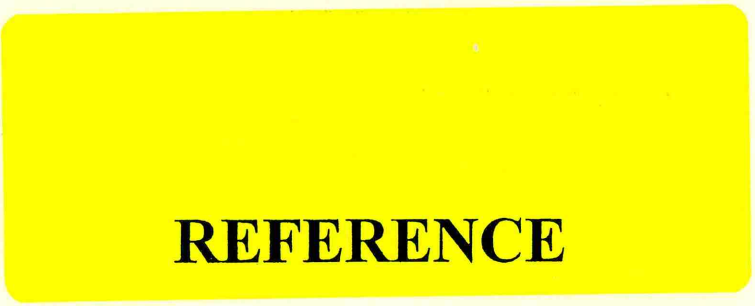

BEST PRACTICES FOR COMPUTER SIMULATION IN HEALTHCARE SYSTEM

BY

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF SHEFFIELD HALLAM UNIVERSITY FOR THE DEGREE OF MASTER OF PHILOSOPHY

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Abstract

This thesis discusses the study of best practices for computer simulation in healthcare system with the aim of developing a customised simulation environment for healthcare resource planning.

Initially a review of the use of computer simulation technology in healthcare industry is conducted using case study analysis method. Number of healthcare oriented simulation applications selected from various sources are analysed using multitude of parameters such as type of models developed, nature of the problem being investigated and type of software used for model development and validation. Based on this analysis benefits and problems encountered in the modelling and simulation of healthcare industry are identified.

Simulation model building process is also discussed briefly and highlighted the issues involved in healthcare oriented simulation modelling. Useful suggestions are made to improve the model building process in healthcare sector. A Number of simulation models related to popular healthcare problems are demonstrated in detail.

Healthcare planning process is modelled using IDEF0 methodology in order to assess the current applications of computer simulation tools within the planning process. This investigation also identified further areas of applications of simulation in healthcare planning.

Based on the findings of the study, specifications and prototype templates for five areas of healthcare industry are created to enable development of a customised simulation environment for healthcare resource planning. Finally some general conclusions and made and work that need to be done in future highlighted.

Preface

This thesis is submitted in partial fulfilment of the requirements of Sheffield Hallam University for the degree of Master of Philosophy. It contain an account of research carried out between April 1999 and February 2002 in the school of Engineering, Sheffield Hallam University, under the supervision of Prof. Terrence Perera.

Except where acknowledge and reference is appropriately made, this work is to the best of my knowledge , original and has been carried out independently. No part of this thesis has been, or is currently submitted for any degree or diploma at this , or any other university.

Manage S.D.U.K.M

June, 2002.

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CONTENTS

Chapter 1

INTRODUCTION

1.1 Background to the research.

Healthcare systems are very complex, and consist of a variety of resources such as people, equipment and buildings. Typically, patients go through a series of processes to obtain the required treatments. Decisions made at each process can be regarded as the commitment of these resources (Mannual, et al., 1999 and Frank, 1994). For example, a heart by-pass operation requires the service of surgeons and nurses and the use of medical equipment. Typically, most of these resources used in other process as well.

In recent years, healthcare systems have been re-organised to improve the quality and the efficiency of services. Although certain improvements have been noticed, it is increasingly becoming difficult to strike a right balance between the cost of providing services against service quality/efficiency. Healthcare managers need to identify the best combination of resources required to meet the expectations of patients at the minimum cost (Hans, et al., 1996, Mark, et al., 1993 and Martin, 1997).

Allocation of resources to healthcare processes is a complex task. Managers need to manipulate a wide a variety of data available in their business systems. Traditionally, mathematically based models are built to process this data and to carry out 'what-if' analysis (Steve, 1997, James, et al., 1994 and Arup, 1991). Charles, (1999) and James, et al., (1994) argue that these models fail to provide accurate information due to over-simplified mathematical relationships.

These mathematical models do not take dynamics of the processes and the inter-relationships between the processes into consideration, hence less accurate information. As an alternative analytical approach, computer simulation based models can provide more accurate information, therefore better decision making.

Computer simulation has become a major decision support tool in many industries. For example, manufacturing industry has immensely benefited from the use of simulation models (Perera , et al., 2000, Timothy, et al., 1992 and Moreno, et al., 1999). Both automotive and aerospace industries consider simulation as a key technology in their businesses.

1.2 Justification for the research

Like in manufacturing industry, healthcare systems typically compose of a sequence activities with varying times randomly (stochastic). For example, the rate of patient arrivals, treatment duration and length of stay and the patient mix are random variables. Hence, decision-making tools should be able to capture that essential randomness found in healthcare systems. Computer simulation is one of such tools (Timothy, et al., 1992, Moreno, et al., 1999 and Perera , et al., 2000).

Although computer simulation has been used for more than two-decades in healthcare sector, recent studies have shown that it has not yet become a key technology in healthcare planning and management (Charles, et al., 1999 and Julie, 1996). Through, an extensive survey of the literature and the discussions with both simulation practitioners and healthcare managers, it has been identified following major shortcomings:

- Lack of understanding of the role of simulation technique use in healthc are systems.
- Lack of healthcare specific simulation environment.
- Difficulties of capturing data from healthcare systems.

1.3. Focus of the Research

During the last two decades, much of the research and applications have been focused on simulation oriented healthcare modelling but it has not been widely used in healthcare system. Also no one except MedMode has made an attempt to develop healthcare specific simulation environment.

MedModel is a healthcare specific simulator package developed by ProModel Corporation. It was designed to be tailor to the needs of healthcare managers, engineers and clinicians (Steve, 1997). According to some modellers, use of this package is not particularly popular due to several drawbacks in the modelling and simulation of healthcare systems such as model limitations, inflexibility and poor integrative capacity with other software applications. In the MedModel simulator package, still modeller has to do some programming and follow the logical steps same as ProModel software. It does not provide user-friendly environment for non-modelling client like healthcare managers, administrators, etc.

- The aim of this research is : **to develop a customised simulation environment for healthcare resource planning.**

To accomplish this aim, it is necessary to:

- Identify best practices and problems encountered in the modelling of healthcare system.
- Develop simulation models for a selected range of healthcare problems to identify the issues involved in model building process.
- Analyse the healthcare planning process and identify the areas where the simulation technology is used. Also identify other opportunities for computer simulation technology in healthcare sector.
- Create specifications for healthcare oriented simulation environment, to accelerate the model building process for healthcare resource management.

1.4. Outline of the Thesis

The chapter1 discusses the introduction part of the thesis. It gives detailed information on background, objectives, justification and out line of the thesis. The literature review and proposed research methodology are discussed in chapter2.

Chapter3 is based on the case study of computer simulation applications in healthcare system planing and management. It highlighted the results of case study analysis using 30 healthcare oriented simulation applications which were published during the period of 1990 to 2000 and provides information on where the healthcare simulation applications were performed, types of models developed, nature of the problems being investigated and trend of applications. Further, it describes advantages, disadvantages and problems encountered during the modelling and simulation of healthcare application.

Simulation model building process and experimental issues related to healthcare oriented simulation modelling are discussed in chapter4. Further, it demonstrates the development of selected healthcare oriented simulation models in details.

The analysis of healthcare planning process using IDEF0 tool is presented in chapter5 and it summarised stages of National health service planning process with current practice and highlighted the other possible areas where computer simulation tool can be applied.

The development of specifications and prototypes for healthcare oriented simulation templates environment is discussed in chapter6. First, it discusses the five areas where simulation tools has been mostly used in healthcare industry and analyses each area according to the structure and job process. Then it identifies the possible processes for healthcare specific simulation templates and developed specifications and prototypes for them. Finally, it discusses the advantages of using templates for healthcare modelling.

Chapter7 of this thesis make the conclusions and suggest areas that deserve further work.

Chapter 2

LITERATURE REVIEW AND RESEARCH METHODOLOGY

2.1 Literature Review

2.1.1 What is modelling

Modelling is the process of producing a model; a model is a representation of the construction and working of some system of interest. A model is similar to but simpler than the system it represents. One purpose of a model is to enable the analyst to predict the effect of changes to the system. On one hand, a model should be a close approximation to the real system and incorporate most of it salient features. On the other hand, it should not be so complex that it is impossible to understand and experiment with it (Anu , 1997).

Figure 1 shows ways to study a system. (Law,1991).

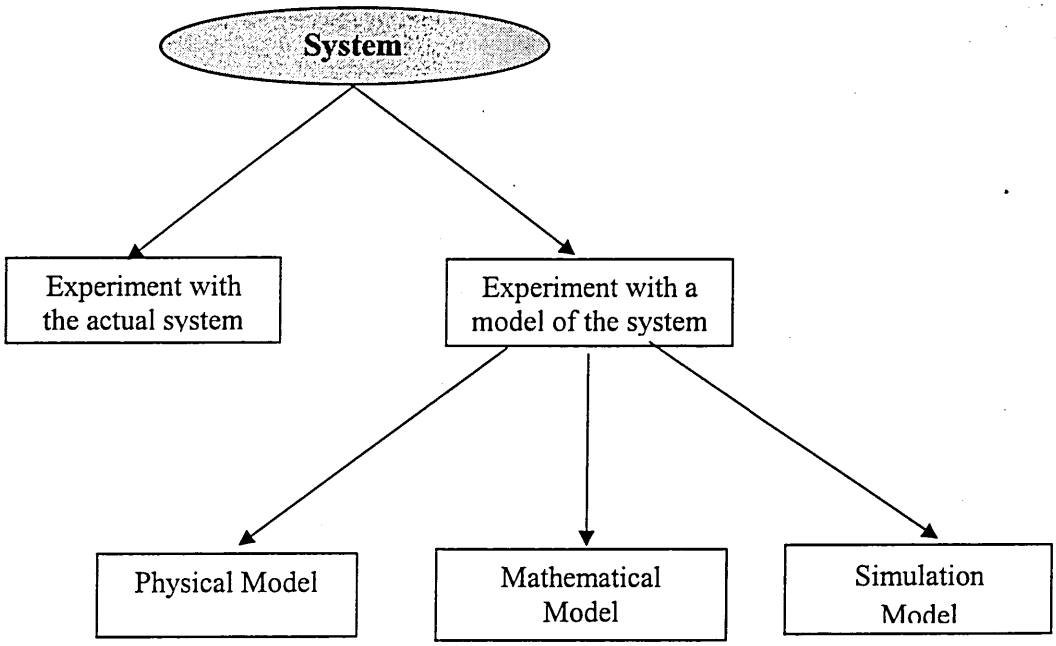


Figure 1: Ways to study a system

A model is often built when it is too costly, too dangerous or even impossible to work and experimentation with a real system. One of the reasons for using modelling is because, it enables the user to get a better understanding of the real system modelled. There are many different ways of modelling a system, one of which is simulation.

2.1.2 What is Simulation

Simulation is one of the most powerful analytical tools that can significantly facilitate the problem solving and decision making process. The definition of simulation is given by Pegden, et al.,(1990) as " the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behaviour of the system and /or evaluating various strategies for the operation of the system". Banks,(1998) , described simulation as follows :

"Simulation is the operation of real-world process or system over time. Simulation involves the generation of an artificial history of the system and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system that is represented. Simulation is an indispensable problem solving methodology for the solution of many real-world problems. Simulation is used to describe and annualise the behaviour of a system and aid in the design of real systems." The Figure 2 describes the simulation study schematically.

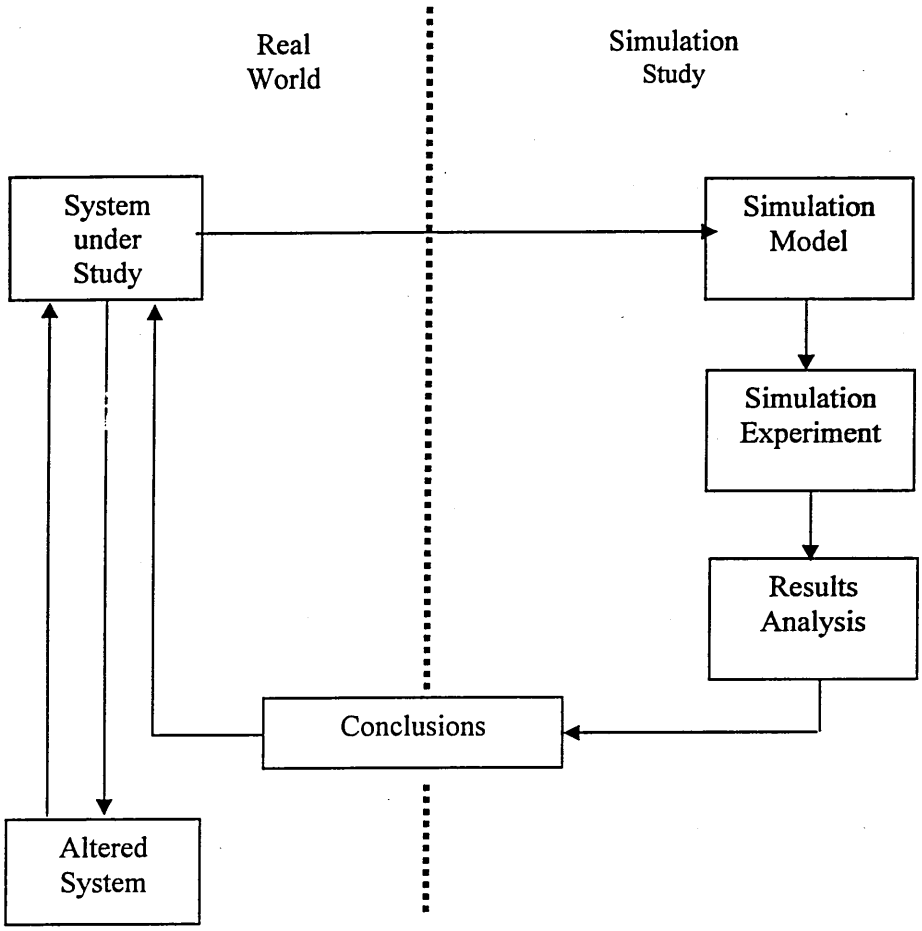


Figure 2 : Simulation Study Schematic (Anu, 1997).

2.1.3 Computer Simulation

Computer simulation is a tool that allows a model of system to be executed on computer. This technology enables one to create a software representation of existing or proposed systems, plans or polices. Computer simulation enables one to analyse and predict system performance under different conditions, even before altering the slightest thing of real-life operations. As computers can model the behaviour of a system over say a few months in a relatively short space of time, a few minutes or even seconds, the attraction of computer simulation as a decision support tool becomes obvious.

One important factor of good analysis though, is that the model should be a close approximation of the real system, although it should not be too complex in order to easily be experimented with. That is the whole purpose of computer simulation. It is used to create models to experiment with so that it is possible to see the outcomes of different decisions made upon the model. It thereby enables the user to foresee effects of alternations and reduce risks and chances of failure, which means that computer simulation, can be very time sparing than economic evaluation and experimental method.

2.1.4 Simulation Models

- **Continuous / Discrete**

The discrete or continuous classification refers to the model variables. Continuous variables may take on the value of any real number, while discrete variables may assume only a limited, specified number of values. Particularly important in this distinction is the time variable in a simulation model. If alteration to the model occur continuously as time varies, classify the model as continuous. If on the other hand, changes occur only at discrete points in time, the model is discrete (Stewart, et al., 1989).

- **Deterministic / Probabilistic (Stochastic)**

When distinguishing between probabilistic and deterministic models the focus is again on the model variables. If random variables are present, classify the model as a probabilistic model. Random variables must be defined by an appropriate probability function. If on the other hand mathematical variables, variables whose values may be stated with certainty, are sufficient to describe the system behaviour, the model is deterministic (Stewart, et al, 1989).

2.1.5 Why simulation is applicable to Healthcare

There are several reasons why simulation is particularly applicable in Healthcare, especially as compared to many analytical methods. Healthcare is best characterised as a stochastic system; randomness occurs in the onset of disease, duration of illness, length of recovery, needs for health resources, etc. Simulation permits the modelling of these statistically uncertain phenomena without restrictions on the distributions used and the way they are analysed. Furthermore, simulation makes possible realistic modelling of the complexity of Healthcare delivery systems.

In Healthcare systems, people serve people and most of the time these service systems can behave in a very complicated fashion, where there may be multiple and varying servers together in a complex network of queues. Analytical models are often too restrictive and inadequately reflect the major features of these operational environments. Compare to optimisation model, simulation does not require a normative statement about the Healthcare delivery system (James, et al., 1994).

Simulation models are easy to present to decision-makers such as hospital administrators , healthcare managers, or doctors, since the model can be described in real terms without resorting to the complications of mathematics and statistics. Such modelling has great face validity, which is important in implementation, especially since health environments typically involve a diverse group of decision-makers.

2.1.6 Healthcare oriented simulation applications

Over the past four decades, simulation has proven to be a significant tool in the analysis of a wide variety of Healthcare delivery systems. Over 30 years ago, Fetter and Thompsion, (1965) as well as Robinsion and Davis,(1968)applied simulation to patient scheduling and other hospital operational management problem.

James, et al., (1994) reported the steady increase of applications during the period of 1975 to 1980. This trend continued through the 1980's and 1990's with more and more applications reported in the literature.

Among the varity of applications, modelling patient treatment process, hospital bed planning, outpatient clinics, critical care and emergency medical systems are seen as the most popular applications.

Despite this steady increase in applications, simulation has not yet become a key technology in healthcare decision making process. According James, et al., (1994) and Julie,(1996), following are the few of major barriers associated with implementing simulation in healthcare:

- lack of understanding of the role of simulation technique,
- Healthcare managers traditional reliance on simpler, deterministic analytic techniques for decision making,
- Administrators and providers resistance to the unfamiliar and dehumanising nature of simulation,
- Highly technical nature of simulation.

2.2 Research Methodology

This section, outline the detail of methods and steps employed in this study and places the work in the context of research methodologies developed and employed by other researchers.

2.2.1. The research methodology employed in this research

To select the appropriate research methods, a close examination of the research questions were required to develop an understanding of the nature of information required to solve them.

During the literature survey and discussions with both simulation practitioners and healthcare managers, major drawbacks/problems (see chapter 1, justification of the research) particularly applicable to healthcare simulation environment were identified. To find out solutions for those problems, one has to ask "what", and "why " type of questions. According to the many sources (Gill and Johnson, 1991), (Glaser and Strauss, 1967), (Yin, 1994), this type of research is classified as inductive or exploratory research and therefore qualitative research methods are the most suitable to be employed.

Normally, qualitative research methods are surveys, case studies (single/multiple) and action research (Powell, 1985). Most of the qualitative research involves first hand face-to-face observation or participation in the environment of the subject of analysis. Taylor, et al., (1984) refer to qualitative methodology as research that generates descriptive data in the form of people written or spoken words and observations. From this data, the researcher forms concepts, insights and understanding; hence qualitative research is inductive by nature. However, a number of authors argue that inductive research methods produce both qualitative and quantitative data.

The methodology employed by this research was composed of two different research techniques such as case studies and action research.

2.2.2.Case Study

Case study research helps us to understand a complex issue or object and can extend experience or add strength to what is already known through previous research (Glaser and Staues, 1967). Case studies emphasise detailed contextual analysis of a limited number of events or conditions and their relationships. According to Eisenhardt, (1989) and Stake, (1995), case study is a research strategy which focuses on understanding the dynamics present with single settings and it can involve either single or multiple cases.

Case study method has been employed as a useful research technique by different authors including Baker, (1988), Goode and Hat, (1952), Glaser and Staues, (1967), Hamel, (1993) and Yin, (1984) for many years across a variety of disciplines. Social scientists, in particular, have made wide use of this qualitative research method to examine contemporary real-life situations and provide the basis for the application of ideas and extension of methods. Yin,(1984) defined the case study research method as an empirical inquiry that investigates a contemporary phenomenon within its real-life.

Many well-known case study researchers such as Rober E, Helen Simons and Yin, (1984) wrote about case study research and suggested techniques for organising and conducting research successfully. According to their suggestions, following are the major steps that have to be followed in every case study.

- Determine and define the research question
- Select the cases and determine data gathering and analysis techniques
- Prepare to collect the data
- Collect data in the field
- Evaluate and analyse the data
- Prepare the report.

In this research, case study technique used as one of the research method to analyse the popularity of computer simulation applications in healthcare industry. This analysis based on the 30 healthcare oriented simulation applications developed during the past decade (1990 to 2000).

2.2.3 Action Research

Gill and Johnson, (1991) defined action research as " research projects which are undertaken to solve specific managerial problem and, at the same time, to generalise from the specific and to contribute to the theory". The role of the researcher differs from basic case study research in that the researcher is interacting with the organisation in a role similar to that of consultant. However in consultancy , the client or organisation presents a set of problems and defines goals inviting the consultant to solve them. Whereas in an action research situation, the definition of problems and their solutions is a collaborative effort.

According to the Gerald, (1983), The action research process can be described as follows:

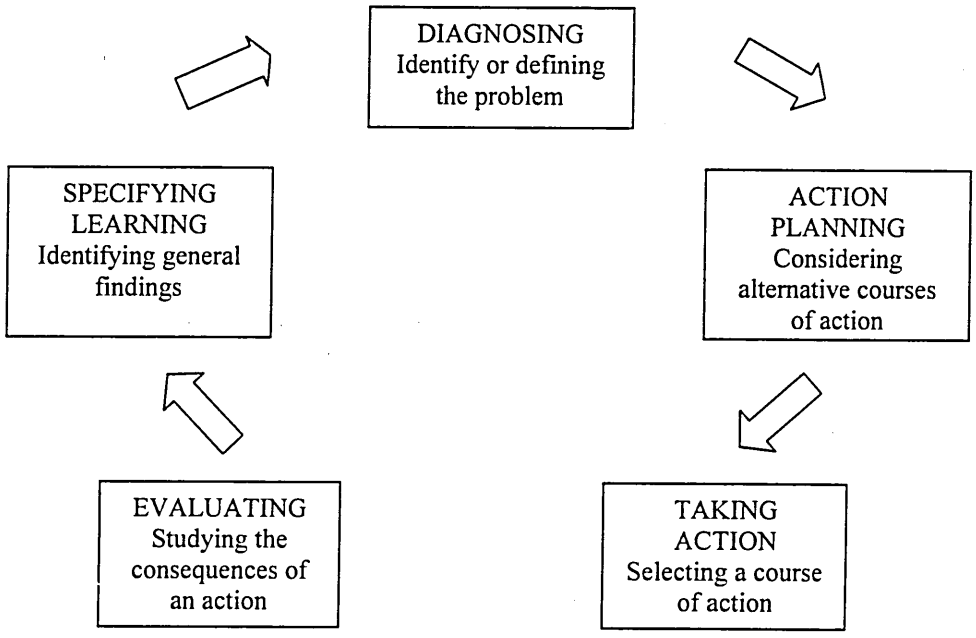


Figure 3, The action research process (Gerald, 1983)

In this study, action research method was used during the analysis of England Healthcare planning process using IDEF0 function modelling techniques (chapter5). The following figure describes the steps use in chapter5.

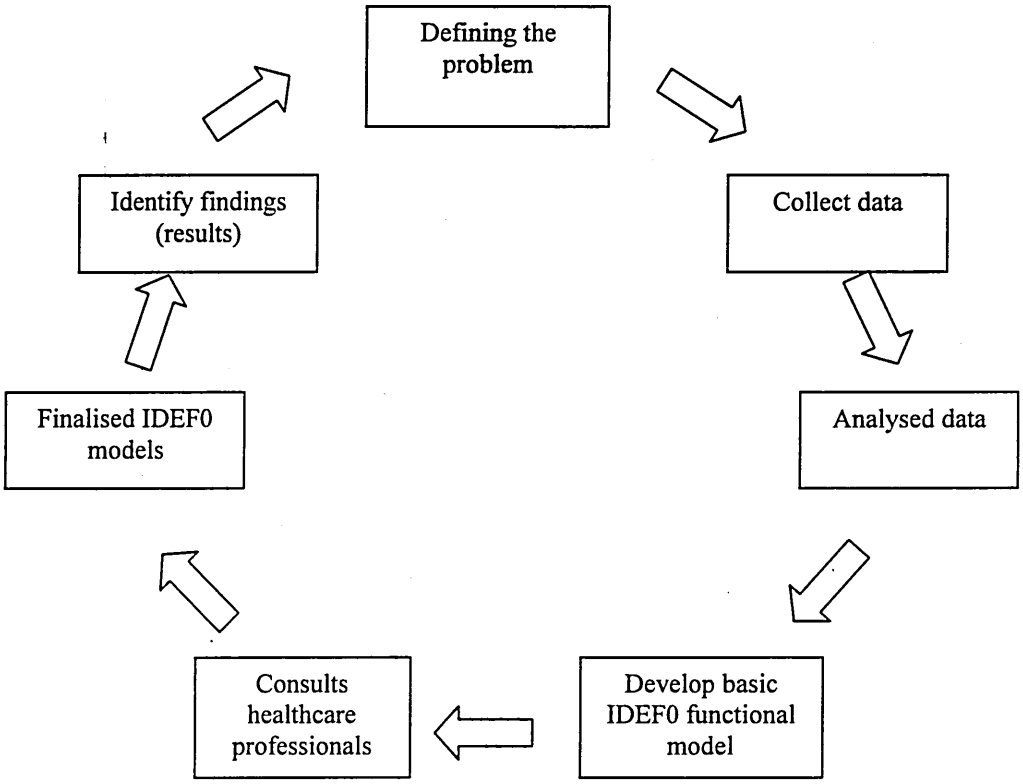


Figure 4 : Research process use in chapter5

The following figure briefly describes the methods and steps employed in this research project.

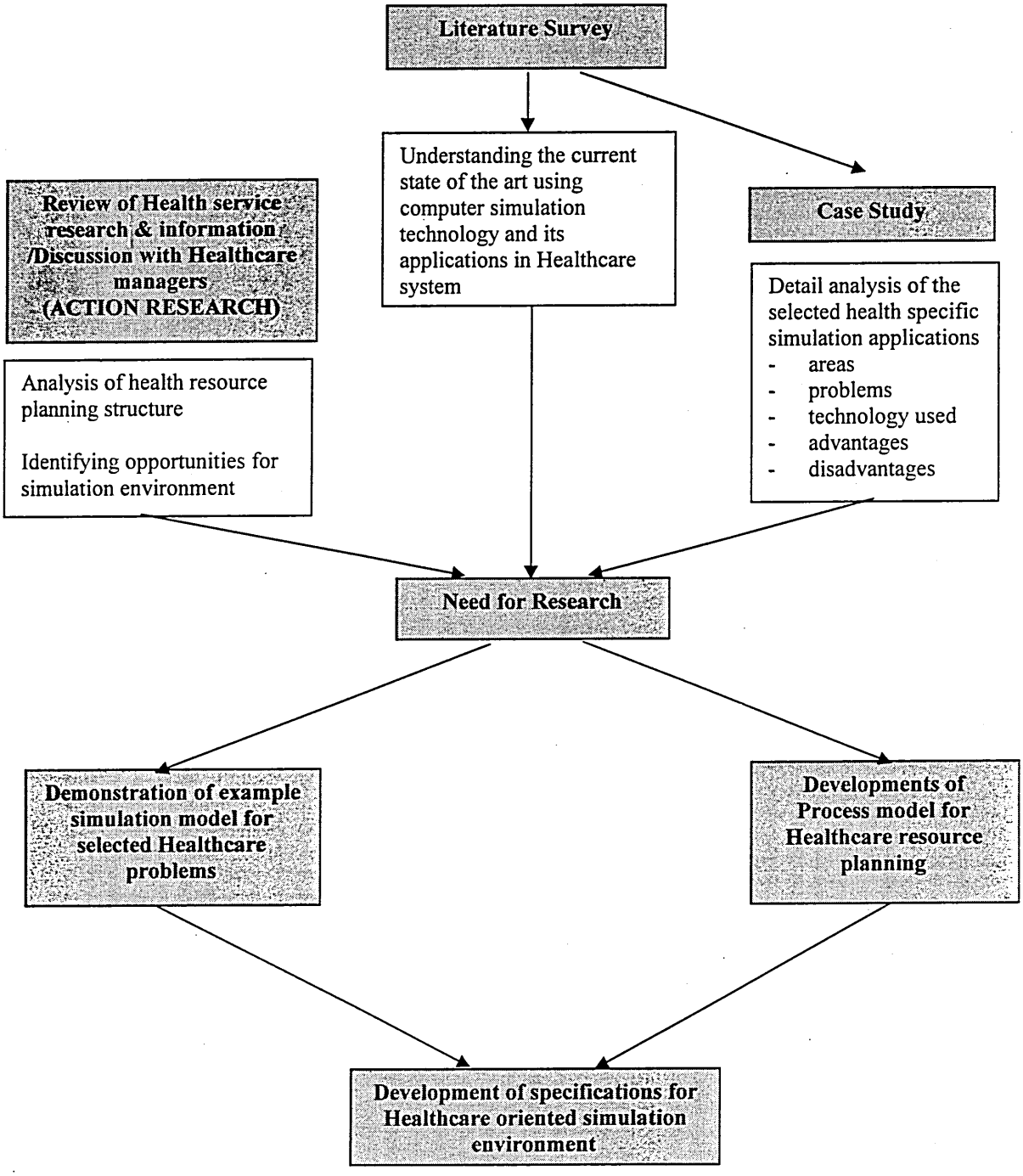


Figure 5: Methods and steps involved in this study

2.3 Discussion:

This chapter described the results of literature review and the research methodology used in this research. Next chapter (chapter3) is based on the case study of computer simulation applications in healthcare system planning and management and it will provide information on where the healthcare simulation applications were performed, types of simulation models developed, nature of the problem being investigated and trend of applications.

Chapter 3

DETAIL ANALYSIS OF THE SELECTED HEALTHCARE ORIENTED SIMULATION APPLICATIONS

(Case study)

3.1 Introduction

Computer simulation is one of the most valuable management decision support tools for planning and evaluating process and resource changes. It is one of the most widely used decision support tool presently available with a wide variety of industries having benefited from such analysis.

The problems faced by healthcare system have attracted the attention of simulation modellers and the application of simulation to healthcare is growing. There are several reasons why simulation applications are particularly applicable in healthcare, in comparison to analytical methods. According to James, et al.,(1994) and Timothy, et al., (1992) healthcare is best characterised as a stochastic system; randomness occurs in the onset of disease, duration of illness, length of recovery, needs for health resources, etc. Simulation permits the modelling of these statistically uncertain phenomena without restrictions on the distributions used and the way they are analysed. Also a simulation model can be used to experiment with systems which are not yet in existence, or to experiment with existing systems without actually altering the system.

This chapter describes the results of case studies analysis related to computer simulation applications on healthcare industry. This analysis is based on the 30 healthcare oriented applications developed during the past decade (1990 to 2000)

3.2 The aim of this case study is:

To review discrete-event simulation applications in healthcare systems and to identify best practices, advantages, disadvantages and problems encountered in modelling and simulation.

3.3 Selection of Publications for the study

In this study, 30 research papers related to Healthcare applications have been selected from different Journals and conference proceedings. During the selection of publications the following criteria were applied.

3.3.1 Selection of recent publications, since 1990

Prior to 1990 and in the early 1990's, most of the simulation models were developed using advanced computer programming languages and those models were difficult to understand for non-modelling client or decision makers such as doctors, nurses or hospital administrators. As a result, such models were rarely practised in healthcare system and their validity is not so well established.

During the past decade, there has been tremendous progress in the development of new computer and information technology. As a result of this, new simulation technology and windows based software were developed. Most modern simulation tools now provide an interactive graphical interface for model definition as well as real time graphical animation. Considering these effects, only the publications of 1990's were selected to identify the best practices .

3.3.2 Selections of publications on direct simulation applications in healthcare

Complex simulation applications such as those that combine operational research methodologies were not considered, because they are difficult to understand for non-modelling clients or decision-makers like doctors, nurses, or hospital administrators. If the model is not complicated, it has significant face validity, which is an important factor in the implementation process, especially since healthcare environments involve a diverse group of decision makers. In view of this fact during the selection of publications for this study, it was decided to select publications that contain healthcare oriented direct simulation applications.

3.4 Analysis of the results of the study

Analysis of the results of this study is structured into two main categories:

- Individual analysis
- Group analysis

3.5 Individual analysis:

In this analysis, each application was analysed according to its title, authors, published year, objectives, software/ language used and type of model developed. The remarks section, describes more details such as modelling issues, limitations, validation, experiments etc for each application (see appendix A).

3.6 Group analysis:

This, list the results of overall study according to following key words:

- Source and year of publications,
- Field(s) of application within healthcare by year,
- Type of models developed and the nature of the problem investigated,

3.6.1 Source and Year of Publication :

Under this study, 30 simulation applications were collected from both healthcare and simulation sources (Table 1). 70 % of the applications came from Conference proceeding and 30% from journals. Out of these 30 `applications 60% of the applications were published during the period of 1996 to 1999 (Chart 1). During the selection process attention was given to Winter Simulation Conference Proceedings, as Winter Simulation Conferences are the gathering points for most modellers to discus different areas of current simulation approaches used in present world.

	Publication	Percentage of Number
	Conference Proceedings	
1	Winter Simulation Conference (WSC)	53
2	Healthcare Information Management System Society-Conference (HIMS)	10
3	SCS Western Simulation Multiconference on Simulation in the Health Science and Services	3
4	Industrial Engineering Conference	3
	Total	**70**
	Journals	
1	Journal of Management in Medicine	10
2	Journal of the Healthcare Management Science	7
3	Journal of the Society for Healthcare System	3
4	Simulation	3
5	International Journal of Healthcare Quality Assurance	3
6	Simulation Practice and Theory	3
	Total	**30**

Table 1: Source of Publication

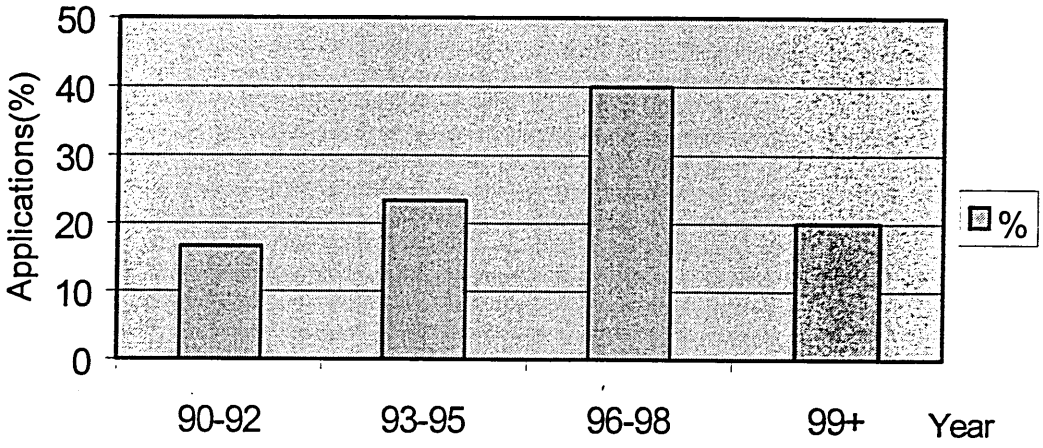


Chart 1: No.of Applications by the Year

3.6.2 Simulation Applications within Healthcare

During the last ten year period the Emergency care / Critical care area has become the most popular field in healthcare simulation applications reporting 30% (Table 2). According to some modellers, a significant percentage of a hospitals total admission comes through the Emergency Department and this area holds a great deal of potential for simulation applications due to the complex nature of patient flows (Julie,1992, Mannuel, et al., 1999 and Frank, 1994).

Also the development of simulation models for field of Laboratory, X-ray and Pharmacy has been quite popular during this period (24%). According to healthcare managers, units of Laboratory, X-ray and Pharmacy play a vital role in hospital environment providing supporting services to other major departments. Most of the time efficiency of the major departments depend on those units (Gene, et al., 1992, Mark, et al., 1993 and Carig, et al., 1995).

Almost 20% of the models considered related to fields of Hospital Administration and Management. These were developed during the period from 1990 on wards, of which 13% were developed in the later stage of this period between 1996 and 1998. According to some modellers, demand for healthcare facilities are increasing and healthcare

managers/administrators are struggling to find out a possible tool to manage healthcare activities efficiently and effectively (Martin, 1997).

In examining the trends in the development of applications, fields of Emergency care/Critical care and Laboratory/X-ray/Pharmacy have been the major focus during the first half of this decade. In the latter half of the decade, the popularity of the development of simulation applications moved to other areas in the field of healthcare.

During the period of 1996 to 1999 , 16% of applications were developed in the field of Hospital Administration/ Management and 13% of applications were developed in the field of Primary care and Out Patient Clinic, as against the relatively lower percentages in the early part of the decade.

	Field / Area	**Year**				**Total (%)**
		1990 - 1992 (%)	**1993 - 1995 (%)**	**1996 -1998 (%)**	**1999-2000 (%)**	
1	Emergency care / Critical care	7	13	7	3	**30**
2	Hospital Administration/ Management	3		13	3	**20**
3	Laboratory/ X-ray/ Pharmacy	7	7		10	**24**
4	Primary Care/ Out patient Clinic		3	13		**16**
5	Family Planning / Maternity wards			3		**3**
6	Health System Planning/ National Policy Analysis			7		**7**

Table 2: Field(s) of Healthcare simulation application

3.6.3 Type of model(s) developed and nature of the problem investigated

According to table 3, during the period of 1990 to 2000 development of models to analyse the problems of Facility Planning / Staffing and Utilisation was the most popular area of the healthcare simulation applications reporting 30% of total study applications deal with this aspect.

Under the problems of Facility Planning / Staffing and Utilisation, modellers analysed the various staff schedules, for doctors, nurses, technicians etc and equipment levels to analyse the corresponding impact on patient throughput and resource utilisation.

Next popular area is the analysis of the problems of Admission/ Patient Scheduling constituting 27% of the total applications. Several alternative decisions rule for patient scheduling have been considered and analysed to determine ways to increase patient throughput, resource utilisation and reduce patient waiting time

Up to 23% of the models were developed to analyse the problems of affecting management needs/Policy analysis and evaluation. Under this category most of the modellers analysed the clinical and administrative policies for different types of patient to improve the patient placement process. Some of the modellers also used simulation as a tool for investigating Operation Management strategies in the different units of a hospital (Arup , 1991).

Simulation models are considered as ideal for assessing the performance of strategic, tactical and operational policies for hospitals and they can validate a proposed policy, un-cover fallacies of a proposal, or determine the sensitivity of the response to a policy change (Timothy, et al., 1992).

	Problem Identified / Model Developed	Year				Total (%)
		1990 - 1992 (%)	1993 - 1995 (%)	1996 - 1998 (%)	1999-2000 (%)	
1	Facility Planning/ Staff utilisation and waiting time		10	13	7	**30**
2	Admission / Patient scheduling and waits	7	7	13		**27**
3	Management needs / Policy analysis/Evaluation	10	3	7	3	**23**
4	Resource Allocation/Planning/cost - benefit analysis			7	3	**10**
5	Transportation / Delivery system/other		3	3	3	**10**

Table 3 : Type of model(s) developed and problem being investigated.

3.6.4 Type of Language / Software used for model development and validation.

During the last ten years period, there has been a significant improvement in the use of a wide range of languages and software for the healthcare model development process (Table 4).

ARENA/SIMAN, a general purpose discrete - event simulation environment became the most popular language for healthcare applications reporting 27% of total applications studied. According to modellers, this language provided a flexible modelling facility across a wide range of problem domains and is considered very simple to learn and use. It also provided a complete simulation environment that supports all basic steps in a simulation study. According to table 4, 13% of the modellers used MedModel software for healthcare applications.

MedModel is a healthcare specific simulator package developed by Promodel Corporation. It was specially designed to be tailorable to the needs of healthcare managers, engineers and clinicians (Steve, 1997).

MedModel provides normal simulation tools with a graphics library which allows developers to produce a clear and compressible user interface. According to some modellers (Moreno,et al., 1999), this application has several drawbacks in the modelling and simulation of healthcare systems:

(a) Objects only support a reduced number of possible actions,

(b) The process is defined through the graphical description of the path followed by the elements inside the organisation,

(c) The modelling of some details is always imposed. However, there are cases where these details are irrelevant for the simulation,

(d) Information of the objects is given through a number of prefixed statistics. However, it is not possible to add other functions. For instance, it is not possible to obtain the length of a waiting queue,

(e) Storing the state of the system at a particular time and simulating from a state previously stored are very useful tools that MedModel does not incorporate,

(f) Communication with other applications is not supported in MedModel.

	Simulation Software	Year				Total (%)
		1990 - 1992 (%)	1993 - 1995 (%)	1996 - 1998 (%)	1999-2000 (%)	
1	ARENA/ SIMAN	7	3	10	7	**27**
2	MedModel		3	10		**13**
3	GPSS	7	3	3		**13**
4	SIMSCRIPT/ WITNESS	3	3	7		**13**
5	MODSIM/ SLAMYS		3	3	7	**13**
6	Visual Sim. / Orca Ines/SimPLE-1		7	3		**10**
7	Other language			3	7	**10**

Table 4 : Language / Software use for model development and validation.

3.6.5 Site(s) where the Applications were performed

As seen in table 5, during the period of 1990 to 2000, Hospitals were prominent as the place where most of the healthcare simulation applications were performed, making up 60% of the total application. Medical Schools and University Health Service Centres came next making up 27% of the total applications.

	Site	Total (%)
1	Hospitals	60
2	University Health Service/ Medical School	27
3	Community Health Centre/Primary Healthcare	10
4	Regional / National	3

Table 5: Site(s) where the application was performed

3.6 Benefits of applying simulation models in Healthcare Management

Computer simulation is one of the most valuable management tools to take effective decisions using scarce resources. Specially it has the following benefits in using it as a tool for Healthcare Management process.

3.6.1 One of the valuable decision support tools

Presently the majority of the healthcare managers / administrators are taking decisions based on analytical tools and static models using massive databases. In an analytical model, most of the decisions in planning rely on judgements. Analytical tools can help focus that judgement on the most significant decisions and provide a method for estimating the implications of planning decisions on operational performance. Finding an analytical tool that can handle the exhibited complexities of healthcare systems has proven to be a daunting task.

Static models depict the activity flow of the systems that define roles and actions to be taken by various providers during each phase of patient processing. While such methods add to the knowledge base of what activities are required, the interrelationships among the activity paths are difficult to model and predict.

Using massive databases, databases record and correlate all manner of clinical and administrative information. Although accurate in recording information on workload, staffing, patient mix, capacity and policy as they relate to cost and quality, the disadvantage of databases is that they are often unable to provide the true correlation among to these factors and the dynamic interaction of each upon the other is usually lost. Also the database approach relies heavily on past performance and is less helpful for predicting the result of anticipated changes to the system (Steve, 1997, Tesham and Ungar, 1996).

Simulation is the most suitable tool to overcome the above difficulties and it can describe complex and dynamic systems such as healthcare easily. It is a powerful problem solving technique widely used in a variety of systems to their benefit.

3.6.2 Easy to Present to non-modelling client

Simulation models are easy to present to non-modelling clients or decision-makers such as doctors, nurses, or hospital administrators and also provide effective training environment which will not impact on operations and will compress much simulated experience into a short period.

3.6.3 Tool with double function

In order to solve the problems, healthcare managers / administrators need a tool with a double function. On one hand, it allows him/her to obtain summarised information about the system state through graphs and reports. That is , the tool automatically analyses and prepares the hospital information in order to facilitate its study by the management. On the other hand, the tool will allow him/her to try different control actions (resource redistribution) so that the manager can observe the effects of any new actions. Therefore, the best decision to approach each situation can be taken because the evolution of the system has been previously predicted. The simulation tool is a piece of software, which provides this duality (Moreno, et al., 1999).

Also simulation models have the following general advantages compared to other Decision making tools:

3.6.4 Experiment with systems which are not yet in existence

Simulation model can be used to experiment with systems which are not yet in existence, or to experiment with existing systems without physically altering the system.

3.6.5 What -if analysis

Also it is one of the best tools to overcome the difficulties in healthcare management systems. Compared with other tools, it will enable healthcare manager and managers to assess the impact of alternative policies and to identify the best solution for a given scenario.

3.6.6 Easy to make decisions

It can also make extremely valuable contributions to decisions by serving as a means of documenting assumptions, organising the decision making process, and identifying potential problem areas. It is amazing how much time is spent in the planning process (especially in meetings) arguing over differences of opinion, where these differences are due to disagreements over assumptions never actually started or acknowledged. Without a structure for identifying and documenting the numerous assumptions underlying decisions, it is impossible to conduct a meaningful discussion of the alternative solutions. The process of simulation provides such a structure (Julie, 1996)

3.7 Disadvantages & modelling issues :

A summary of disadvantages and modelling issues related to healthcare modelling and simulation is given below. These issues are discussed in more detail in chapter4.

- Data poor environment
- Communication gap
- Does not provide the single best answer.
- Inadequate Models
- Less interest
- Lack of knowledge
- Poor start

3.8 Discussion

This chapter discussed the results of reviewing study on simulation applications used in the healthcare system during the last decade. Applications were classified according to the areas applied in the healthcare system, type of models developed/ kind of problem investigated, type of software/ programs used for model development and place where the application were performed. Further it described the benefit of applying simulation tools in healthcare management processes and listed some modelling and experimental issues unique to healthcare delivery application.

During the last decade, a number of applications were developed in several areas of the healthcare system and different kinds of problems have been investigated.

The variety of simulation applications used in healthcare is increasing. A wide Variety of computer languages and software have been used for model development and validation process. At the beginning of the last decade healthcare oriented simulation software, MedModel was developed but use of this software is not particularly popular due to several drawbacks such as model limitations, inflexibility and poor integrative capacity with other software applications. Further research is needed to fill the gaps.

Healthcare is a highly complex system and it has several subsystems to carry out its function. Research initiative need to be developed to find relevant areas of healthcare system where simulation tools are not yet fully functional.

Most of the models reviewed here are developed by academic staff, researchers and students from different universities. Involvement of staff from healthcare oriented institutions has shown little progress. More co-operative approaches need to be developed for integrating academic research with the needs of healthcare managers to develop fully functional simulation models.

Most of the models reviewed here were developed for the analysis of problems for single department or section of a healthcare institute, i.e emergency dept, X-ray unit, Laboratory, etc. Development of multiple aspect simulation models integrating several areas or several sections of the healthcare sector should be encouraged. There is a need to extend the life cycle of simulation to cover both design and operation of healthcare system.

In the healthcare system, one of the many difficulties faced by simulation modellers is poor data availability. Therefore simulation techniques need to be developed to integrate with other information technology tools in order to overcome these difficulties.

Next chapter (chapter4) discusses the simulation model building process and experimental issues related to healthcare oriented simulation modelling. Further, it demonstrates the development of selected healthcare oriented simulations model in details. It will be facilitated for healthcare professionals to understand the use of simulation technology and issues involved in the model building process.

Chapter 4

DEVELOPMENT OF HEALTHCARE ORIENTED SIMULATION MODELS

4.1 Introduction :

Since simulation is not widely used in healthcare system, it is difficult for healthcare managers to assess the use of this technology without exposure to a range of healthcare oriented simulation models. Availability of such models will facilitate the potential users to understand the use of computer simulations and the issues in developing a model. The aim of this chapter is to familiarise the use of simulation technology in healthcare system by providing a better environment for the healthcare managers to understand the use of this technology and its issues involved in the model building process.

First part of the chapter, discusses briefly the simulation model building process and issues involved in healthcare oriented simulation modelling. Later on it highlights a number of ways of improving the healthcare model building process. Finally, section demonstrates the development of some selected healthcare oriented simulation applications (models) in detail (see appendix B). These applications (models) were selected based on the popularity and demand of the healthcare industry. ARENA simulation software was used to rebuild some of the above models. Model input data and output results are presented here only for demonstration purpose.

4.2 Simulation model building process

In the literature, different types of methods were discussed by simulation modellers regarding the simulation model building process. Most recently, Averill and Michael, (2001) discuss a seven-step approach for conducting a successful simulation studies. The following diagram presents the above seven-step approach in detail. This will be helpful for healthcare managers to understand the simulation model building process clearly.

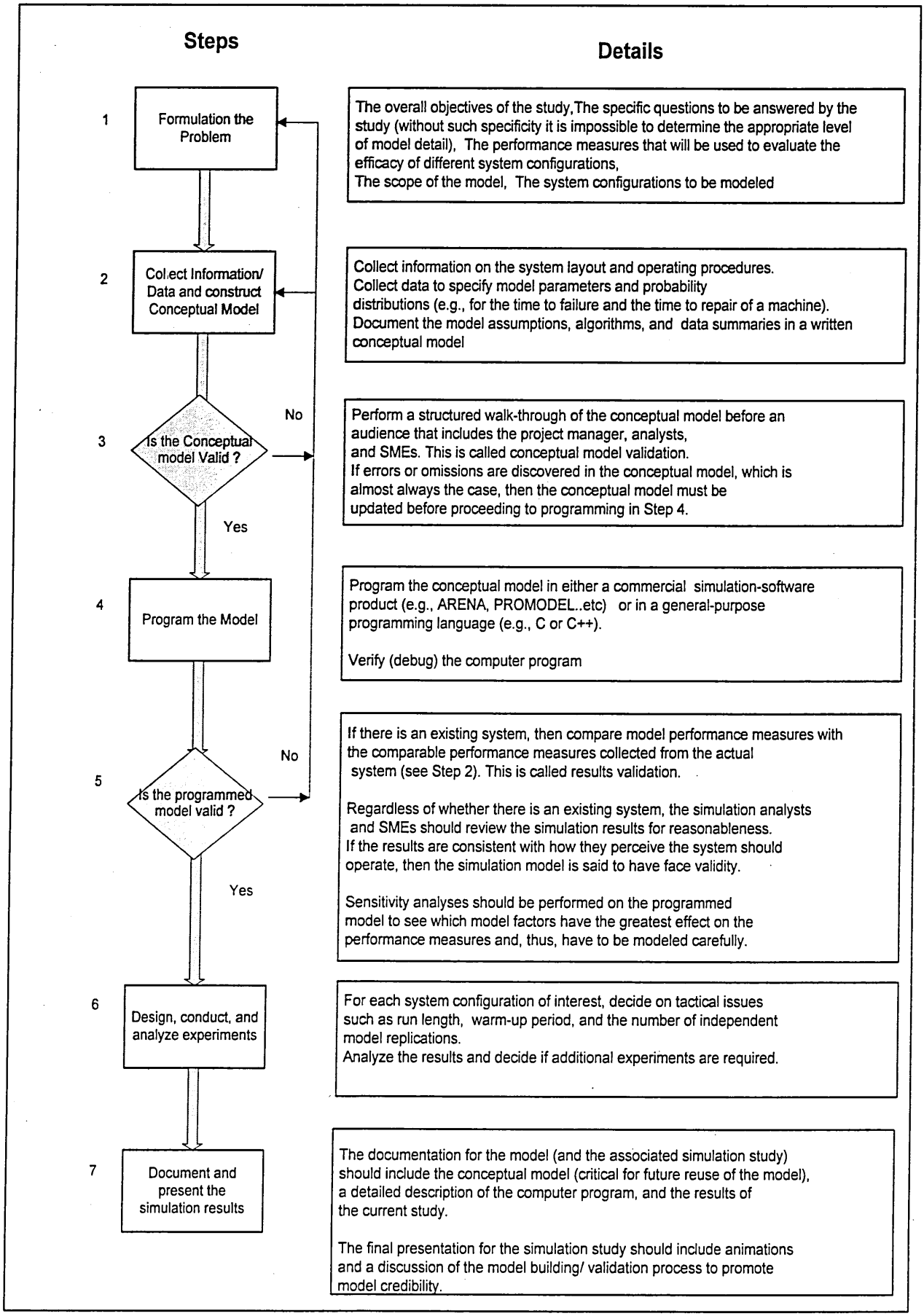


Figure 6: A seven-step approach for conducting a successful simulation study

4.3 Modelling and experimentation issues

(a) Data poor environment

Unavailability of data in healthcare sector is one of the major problem faced by most of healthcare modellers. According to Frank, (1994) data collection is often tedious and time consuming, most of the simulation model building projects is interrupted several times for additional data collection. Catherine, et al., (1997) and Charles, (1999) mentioned that healthcare institutions are not oriented to operations management and generally do not collect data on their service processes. Because of this simulation modellers have to spend considerable time collecting and handling data rather than building and analysing the simulation model

Gerald, et al., (1996) mentioned that they have collected input data from various sources such as patient records, emergency department logs, quality assurance department and direct interviews during the development of emergency department simulation model.

(b) Less interest/ lack of knowledge

James, et al.,(1994) mentioned that most of the healthcare managers and managers are not interest to initiate the simulation projects. This is mainly due to poor knowledge and less familiarity of simulation technology. Some time it is difficult for healthcare managers to understand the content and algorithms of simulation models. Because of this allocation of funds and other resources are limited for simulation studies in healthcare sector.

(c) Poor start

According to Julie,(1996) and Margaret,(1992) some times healthcare oriented simulation studies were not successful due to poor start. At the beginning of the simulation project, it is necessary to identify right problem and to determine the objective(s) of the simulation project clearly. At this stage, modeller also need to decide what system element should be included and what level of details should be

represented. Most of the healthcare simulation projects are created by out side modellers with the help of healthcare managers and they do not clearly understand the healthcare system at the beginning of the project.

(d) Inadequate Models

Steve, (1997) and James, et al., (1997) mentioned that healthcare systems are composed of people serving people. Human behaviour is very difficult to quantify and describe. Thus some hard simulation models just do not simulate actual system behaviour accurately enough to warrant the use of simulation results. Evaluating the success of healthcare systems is not simple to quantify either, so when a model is developed, there is little agreement about whether the model really demonstrates a significant system improvement. Nevertheless, simulation increases the manager's imagination and creativeness in quantifying healthcare systems and progress is being made in this area as models build upon each other's concepts and results. The computer software, simulation methodologies, and hardware systems available today for healthcare modelling have progressed a long way from the earlier fledgling models, but there are still new ideas to be explored in modelling.

(e) Communication gap

Few of the simulation models reviewed in the case study (chapter3), were developed by staff from the healthcare institutions (Steave, 1997, Julie, 1992 and Margaret, 1992). Most of the models were developed by students, researchers from different universities, sometimes in co-operation with a healthcare institution. Sometimes this relationship is not enough to understand the healthcare institution and its processes clearly by out side modellers. Also they do not have more time to follow it up.

4.4. Ways to improve the use of simulation in healthcare applications

(a). Building reference model library:

When new technologies are introduced, potential users wish to see the benefits and limitation of technologies. This can be best provided with a library of applications which can include a variety of case studies. This should enable the newcomers to understand the versatility of simulation, its benefits and limitation. It should also help them to understand the key stages involved.

(b). Creating healthcare oriented simulation environment:

Developing user-friendly program interfaces and healthcare oriented simulation templates is one of the better solutions to improve the healthcare model building process. These will facilitate healthcare managers to understand the simulation technology with least difficulty. It will also decrease the time spent to build the model reducing a number of steps in the model content. Developing models using these type of template is not difficult and doing experiments with such models also easy make it easy to compare with non healthcare oriented template simulation models.

(c) Integration of simulation with existing databases :

In the healthcare system, one of the many difficulties faced by simulation modellers is poor data availability. Some time modellers has to collect input data from several sources within the healthcare institution such as department logs, patient records, quality assurance records, etc. Therefore simulation techniques need to be developed to integrate with existing databases in order to overcome these difficulties. Availability of such a data reduced the considerable time of model building process.

4.5 Discussion:

Clearly the development of user-friendly program interfaces and healthcare oriented simulation templates environment play an important role in accelerating the healthcare model building process.

Building a library of a set of reference models for popular and in demand healthcare problems is essential to increase the knowledge on computer simulation technology among the healthcare managers.

Development of simulation techniques integrate with other information technology tools is most important to over come the difficulties regarding the input data handling.

Good co-ordination and co-operation between the simulation modellers and healthcare managers are important for a better understanding the issues of each other.

The analysis of healthcare planning process and development of IDEF0 functional models for National Health Service planning is presented in next chapter (chapter5) and it summarised stages of National health service planning process with current practice and highlighted the other possible areas where computer simulation tool can be applied.

Chapter 5

ANALYSIS OF HEALTHCARE PLANNING PROCESS

5.1 Introduction.

During the past two decades, a number of applications were developed in several areas of the healthcare system and different kinds of problems have been investigated. But according to Steve, (1997) and James, et al., (1997) still there are more opportunities in healthcare system for application of computer simulation tools..

Due to the complexity of healthcare system, it is not an easy task for simulation modellers or healthcare managers to identify the possible areas for simulation applications without having proper mechanism or tools.

The main aim of this chapter is to identify the areas where computer simulation tool is mostly used in healthcare planning process and other possible areas where computer simulation tools can be applied.

The ICAM DEFinition (IDEF) method is used as a tool to analyse the healthcare planning process and it is one of the possible tools that can be used to model the decisions, actions and activities of an organisation or system. Also it provides powerful environment for communication as well as analysis purposes (Mayer, et al., 1993).

5.2 Data gathering

For the analysis of healthcare planning process, data was collected from several healthcare information databases and publications such as NHS web site, Health department information databases, Healthcare journals., etc. The results of literature review (chapter 2) and the case studies analysis (chapter 3) are also used to identify the role of simulation in healthcare planning process.

5.3 Analysis of National Health Service (NHS) Frame Work, England

According to the structure of NHS frame work in England (see figure 7), the head of the NHS is the Secretary of State for Health in the Department of Health. Within the Department of Health, the NHS Executive is the head office of the NHS. The Executive is responsible for aspects of policy setting, and, through its 8 Regional Offices, is responsible for implementing strategy and managing the performance of the service. It also works with the clinical professions to develop National Service Frameworks for particular clinical areas, which are linked to national action to implement them across the NHS. The Department of Health is accountable to the House of Commons (Parliament) and a number of Parliamentary Committees. As with other public services, concerns of the ombudsman and auditors are referred to a Select Committee of Parliament to whom the secretary of state must answer.

Health Authorities are accountable to the NHS executive and have responsibility for improving the health of the local population and overseeing the effectiveness of the NHS locally. They work in partnership with local authorities and other NHS bodies, taking the lead in drawing up the Health Improvement Program, which provides the framework for the development and operation of local NHS services. Over time, responsibility for the commissioning of most services will pass to the newly created Primary Care Groups. Health Authorities retain responsibility for the commissioning of specialist services.

Primary Care Groups comprise all GPs in an area together with other members of the Primary Healthcare Team. These Primary Care Groups have replaced the previous arrangements for the commissioning of services by Health Authorities and GP Fund holders. Health Authorities allocate funds to Primary Care Groups, and Primary Care Groups have freedom within the framework of the Health Improvement Program to make decisions about the use of those resources. Once established, Primary Care Groups are able to become self-managed Primary Care Trusts.

NHS Trusts are self-governing organisations within the NHS whose function is to provide hospital and community services to commissioning bodies under service agreements. They are managed internally under the direction of the Trust Board, the Chairman of which is appointed by the Secretary of State. Trusts are directly accountable to the Regional Offices.

The Health Authority, local NHS Trusts and Primary Care Groups or Primary Care Trusts are grouped into what is being referred to as a Health Economy or Health System, in order to facilitate co-operation and sharing.(DH NHS white paper)

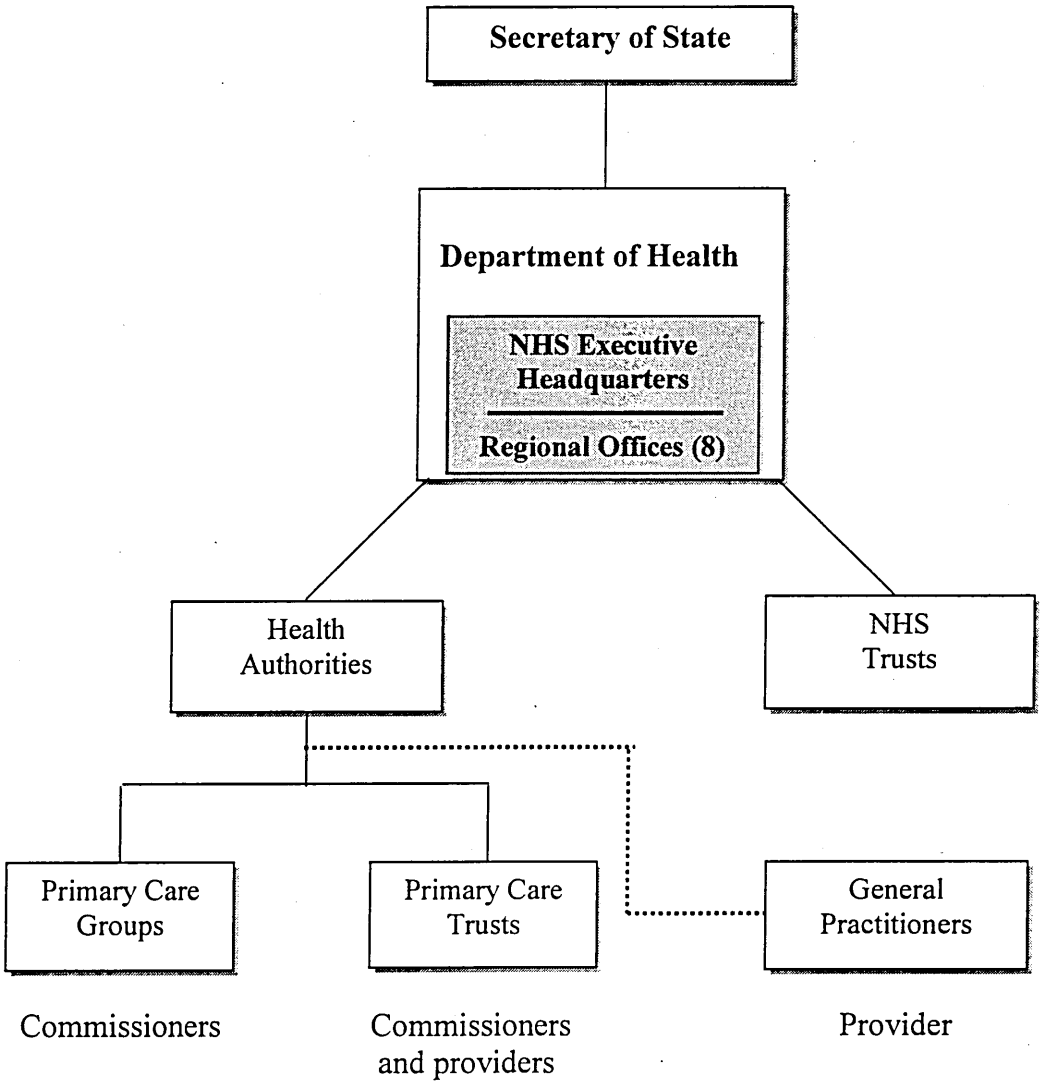


Figure 7 : Structure of the National Health Service, England (DH NHS white paper,1999)

According to the NHS structure, there are six major sections highlighted and their roles and responsibilities are as follows:

The Department of Health

- Formulates Health Policy
- Instructs the NHS Executive Headquarters
- Deals with policy issues of public health
- Advises Ministers
- Manages the relationship with other agencies and statutory bodies

NHS Executive Headquarters

- Sets the NHS strategic framework
- Secures and allocates resources at Health Authority level
- Provides guidance on the implementation of policies
- Reviews the performance of commissioners and providers
- Reports to Ministers

NHS Executive Regional Offices

- Oversee policy implementation and ensure compliance with directives
- Monitor the performance of commissioners and providers
- Approve Primary Care Group allocations
- Arbitrate in the event of disputes

Health Authorities

- Lead the development of the local Health Improvement Program
- Set Primary Care Group allocations
- Manage terms of service of GPs and other independent contractors
- Oversee patient registration with GPs
- Monitor performance of Primary Care Groups
- Commission some services for the local population through service agreements.

Primary Care Groups and Trusts

- Contribute to the Health Authority's Health Improvement Program
- Work with other agencies to promote the health of the local population
- Commission health services from Trusts within the framework of the Health Improvement program
- Develop primary care
- Work closely with Social Services to better integrate primary and community health services
- Level four Primary Care Trusts are also responsible for providing community services

NHS Trusts

- Provide services according to services agreements with commissioners
- Manage delivery of services to quality and activity targets set out in contracts
- Meet value-for-money targets
- Contribute to the Health Authority's Health Improvement Program
- Meet statutory financial duties

5.4 Analysis of NHS planning Process, England

At the beginning of the planning process, national and regional health authorities are responsible for develop national health policies, health strategies and guidelines. They also identify national targets and provide guidance to the local health authority to develop, implement and monitor of Health Improvement Program.

At the local level, local health authorities play greater roles to develop, implement and monitor of Health Improvement Program with the support of other local health bodies according to the national policies and guidance.

The Health Improvement Program consists of three major parts namely Primary Care Investment Plan, NHS Trust Operational Plan and Joint Investment Plan (JIP).
Primary Care Groups (group of General Practitioners, Nurses) are responsible for identify the most health needs, locations and investment requirements for the Primary care Investment Plan. They are also responsible for implement and monitor of their parts of annual plan under the supervision of local health authorities.

NHS Trust groups are responsible for identify activities and investment requirements for NHS Trust Operational Plan. They are also responsible for implement and monitor of NHS Trust Operational plan activities under the supervision of Local Health Authorities.
Joint Investment Plan consists of other health related local activities implement by Department of Social Service, Department of Education etc.

Following figure briefly discuss the roles and responsibilities of each bodies in healthcare planning process.

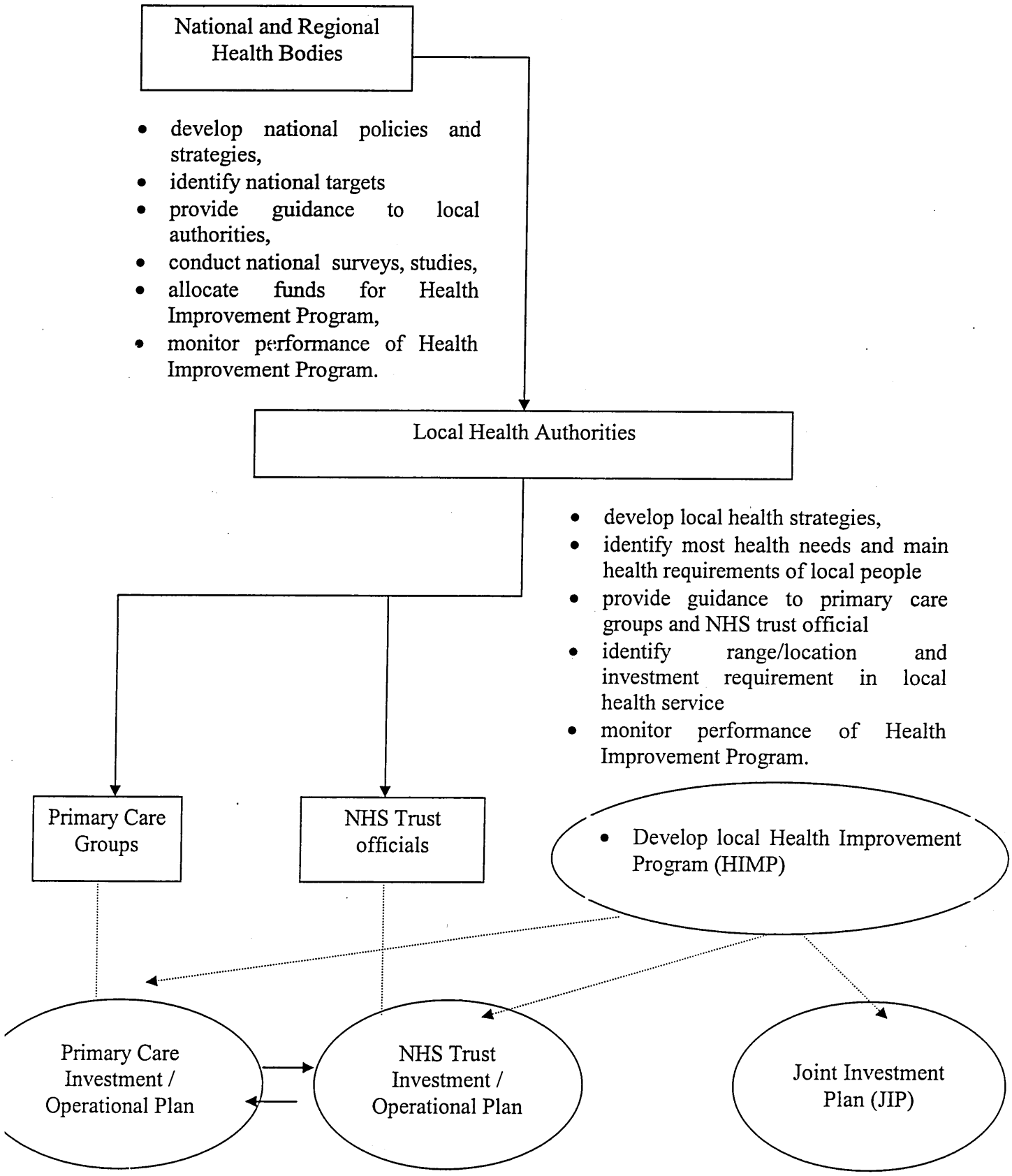


Figure 8 : Analysis of Healthcare Planning Process

5.5 IDEF Technology

The Integrated Computer Aided Manufacturing (ICAM) project of the U.S. Air Force has developed the ICAM DEFinition (IDEF) methods to address the particular characteristics of manufacturing. The IDEF methodology which may be applied to any industrial system that can be expressed as a characteristic of the system graphically. It can be used as support to answer the following three basic questions in order to understand the particular characteristics of a Industrial System (Maji, 1988).

These are :

- What functions are being performed?
- What information and data is needed to support these functions?
- What changes to the functions and information occur over a period of time?

According to the Robert, 1995 the IDEF family of methods describes as follows :

IDEF0	:	Function Modelling
IDEF1	:	Information Modelling
IDEF1X	:	Data Modelling
IDEF2	:	Simulation Model Design
IDEF3	:	Process Description Capture
IDEF4	:	Object-Oriented Design
IDEF5	:	Ontology Description Capture
IDEF6	:	Design Rational Capture
IDEF8	:	User Interface Modelling
IDEF9	:	Scenario-Driven IS Design
IDEF11	:	Information Artefact Modelling
IDEF12	:	Organisation Modelling
IDEF13	:	Three Schema Mapping Design
IDEF14	:	Network Design

Under this research, IDEF0 tools is used to analyse the healthcare planning process and it will describe later on this chapter.

5.5.1 IDEF0 Function model

The IDEF0 function model can be used to model the decisions, actions and activities of an organisation, system or process (Mayer, et al., 1993). It is a powerful tool that can be used for communication as well as analysis purposes. IDEF0 is also a structural functional analysis technique for several industries and it consists of a series of related diagrams organised in hierarchical manner (Mayer, 1992). IDEF0 makes use of the hierarchical cell modelling graphical techniques to describe the functions at the desired level of detail. In a IDEF0 model, the central box represent the activity, described by an activity name beginning with a verb. As shown in figure 9, arrows enter and exit the box. The arrows from the left represent input (I) to a activity and arrows coming out from the right represent the outputs(O) that the activity produces by transforming or consuming its inputs. The arrows coming from the top are controls (C), which constrain or control when or how the activity is accomplished. The mechanisms (M), the resources used to execute activity, enter from the bottom. The arrows in the activity model are known collectively as "ICOMs".

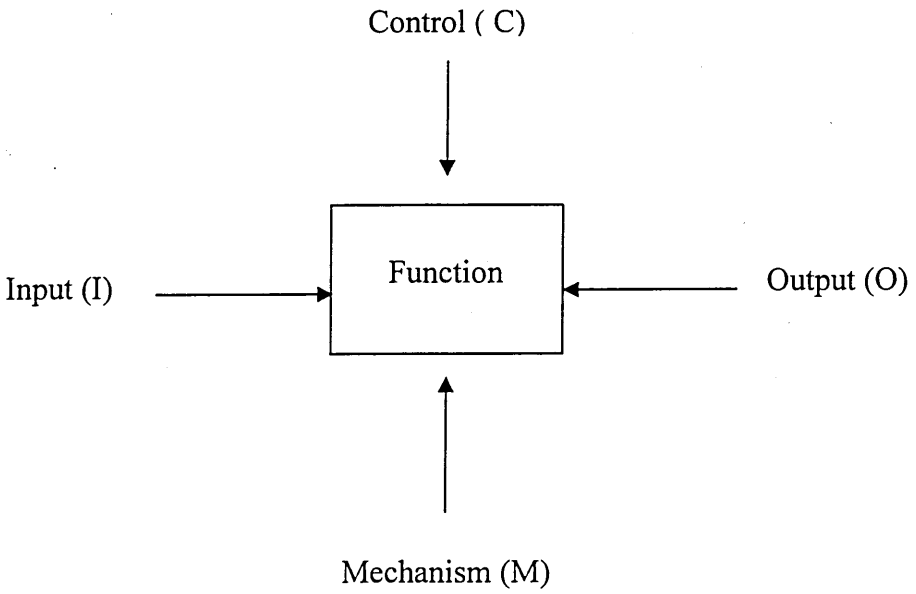


Figure 9: The ICOMs

Normally, the IDEF0 model starts from a general representation of the system. This representation is called A0 diagram. The decomposition process can be performed further, breaking down the A0 diagram into sub-diagrams to describe as required the level of details as shown in figure 10.

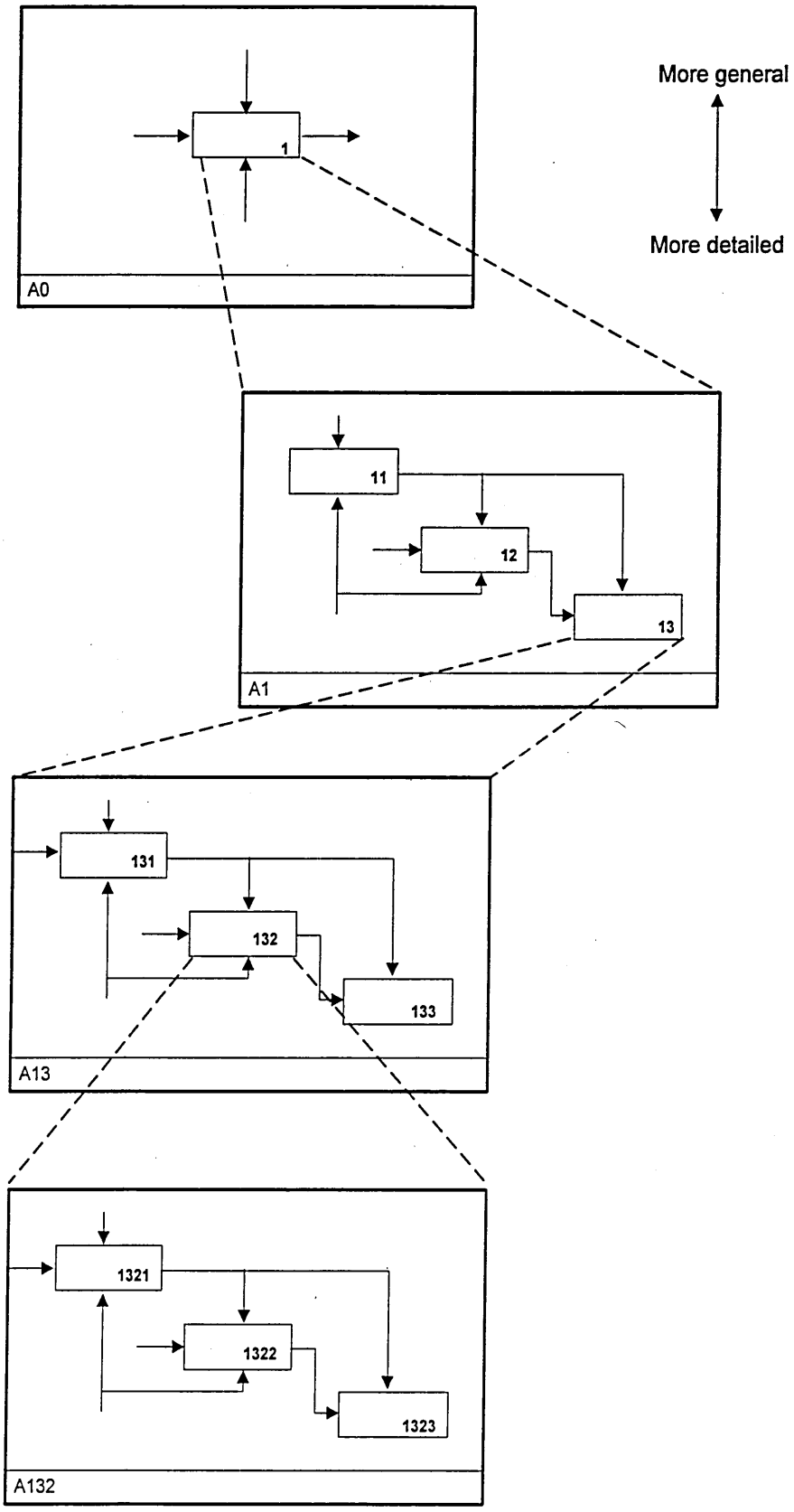


Figure 10 : The decomposition of IDEF0

5.6 Development of IDEF0 Functional models for NHS Planning Process :

This sector describes development of IDEF0 functional models for NHS planning process. The main aim of this development is to identify other potential areas for computer simulation applications.

5.6.1 Development Process

Following figure briefly presents the development process of IDEF0 functional models for NHS planning process.

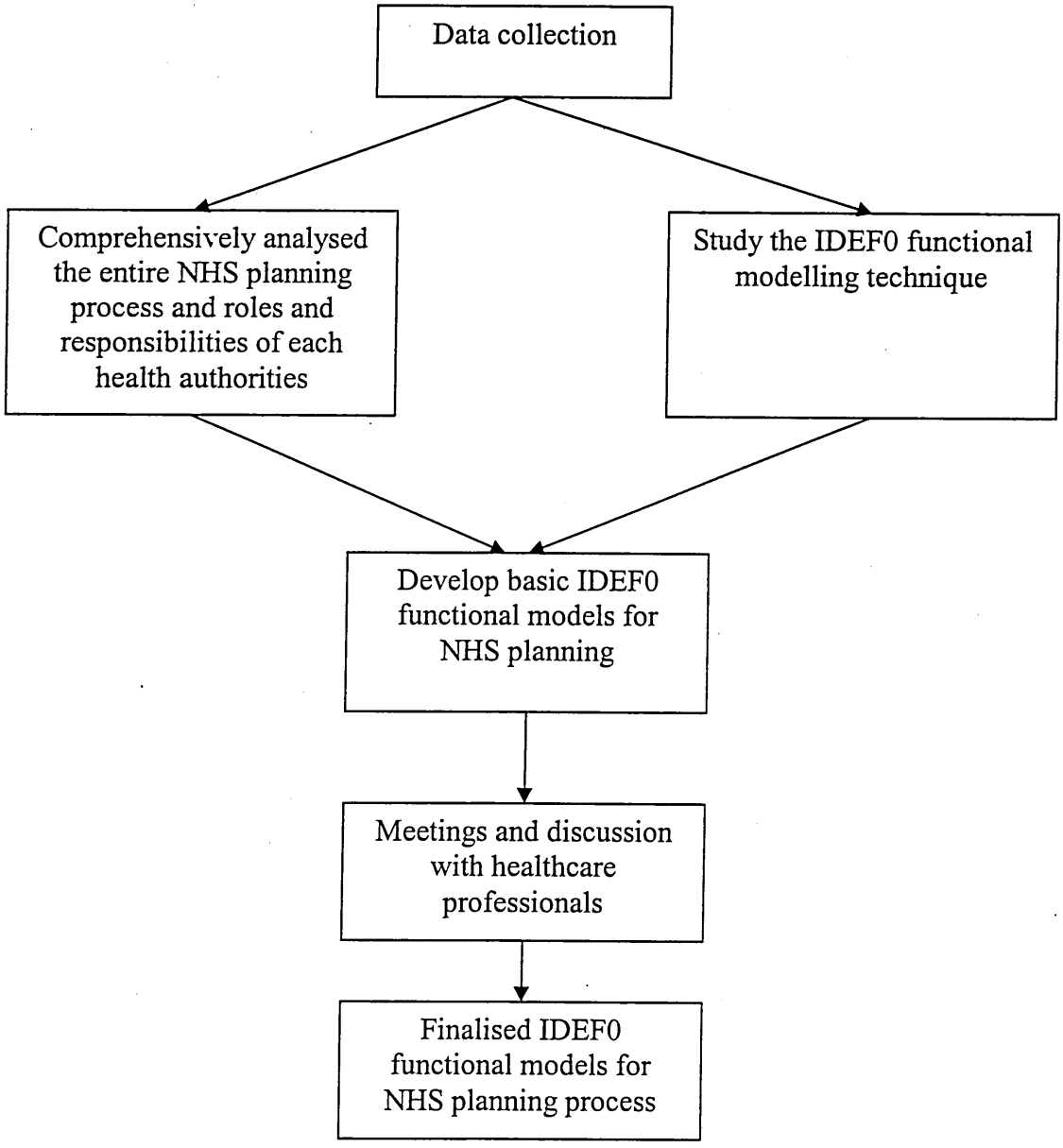


Figure 11: Development process of IDEF0 functional models for NHS planning process.

At the beginning, reviewed the entire National Health Service framework and identified organisation set-up, roles and responsibilities of each body according to structure (pages 39-42). Also comprehensively analysed the NHS planning process and identified its key areas, process, activities and steps involved (pages 43-44). Then study the IDEF0 functional modelling technique (pages 45-48) and transfer the above analysed information of NHS planning process into basic IDEF0 functional models.

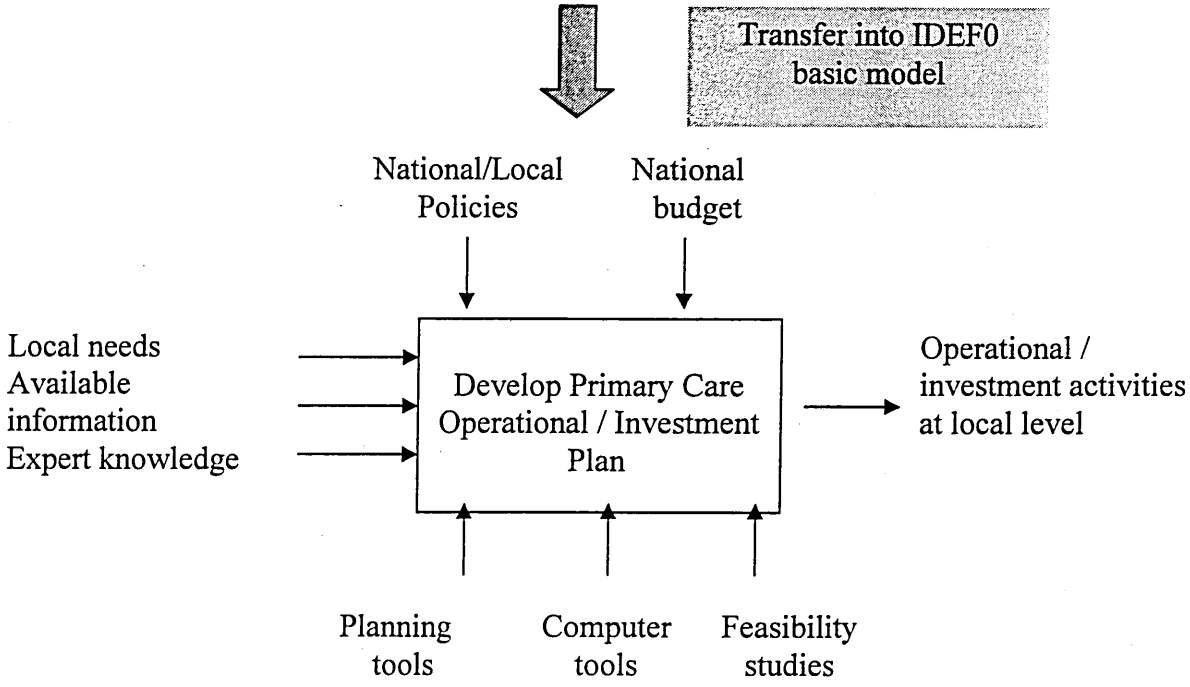
After that consults the healthcare research group in the Sheffield University (ScHARR) and finalised the basic functional models according to their comments and suggestion.

Finally, generate the summary table (table 06) describing all stages of health service planning process with current practice and highlighted the other possible opportunities for computer simulation technology.

Ranking (H,M,L,N) for the summary table was developed and finalised with the group discussions and meetings with the healthcare research group in the Sheffield University (ScHARR).

For example: Transfer of Primary Care Operational/ Investment plan activities in to IDEF0 Functional model

Process	:	Development of Primary care Operational/ Investment plan
Mechanism use	:	Planning tools, Computer tools, Feasibility
Controls	:	National / Local policies/strategies, National Budget
Input	:	Available information, Local needs, Expert knowledge
Output	:	Operational /investment activities at local level



5.6.2 IDEF0 Functional models for NHS Planning Process :

The following diagrams describe the IDEF0 functional models for NHS planning process

Diagram 1 : NHS Planning Process

Diagram 2 : Develop Healthcare Strategies

Diagram 3 : Review of Previous Policies / Programmes/Projects

Diagram 4 : Develop Health Improvement Program

Diagram 5 : Develop Primary Care Investment Plan

Diagram 6 : Develop NHS Trust Operational / Investment Plan

Diagram 7 : Develop Join Investment Plan

Diagram 8 : Implement Health Improvement Program

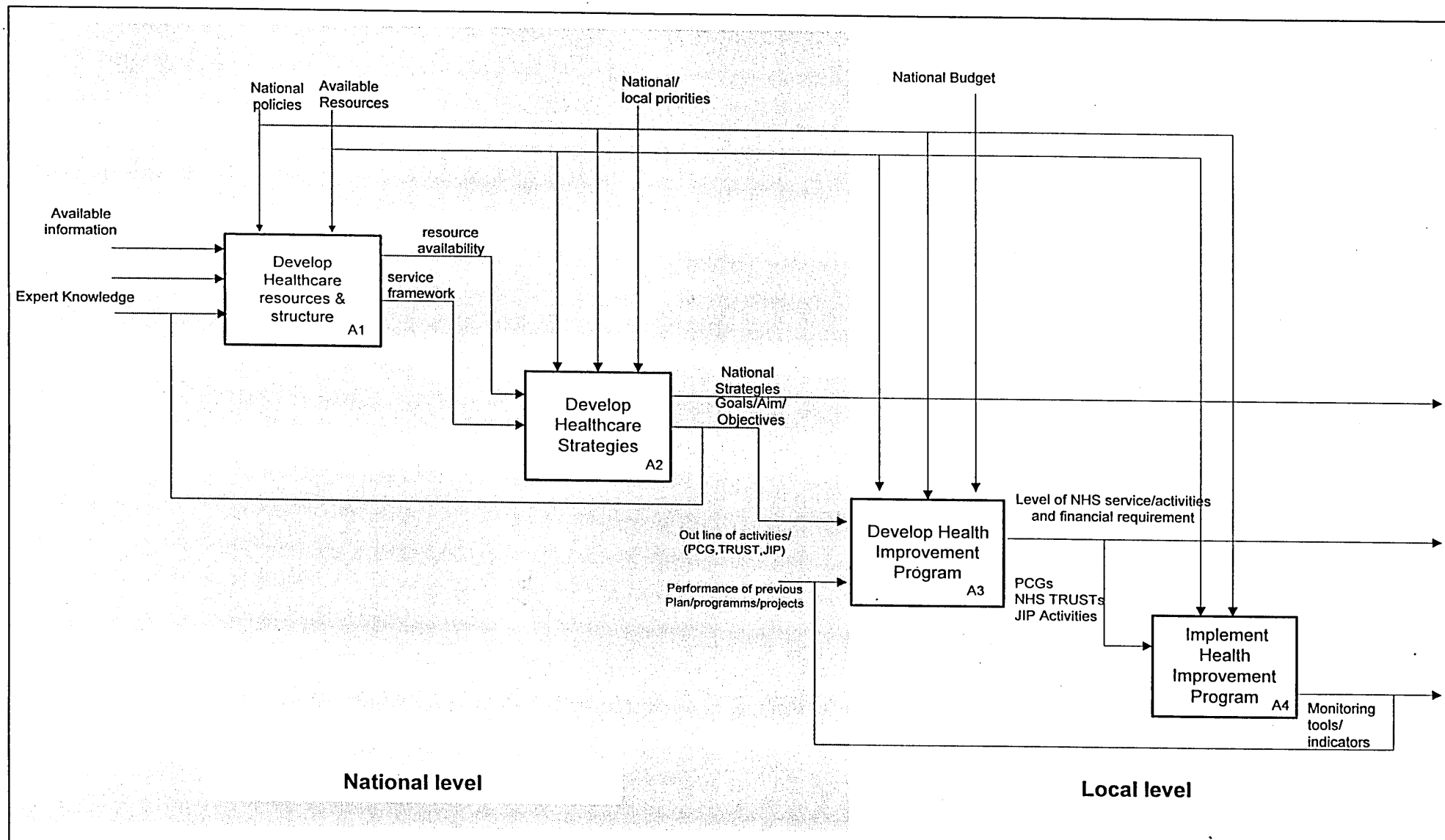


Diagram 1 : NHS Planning Process

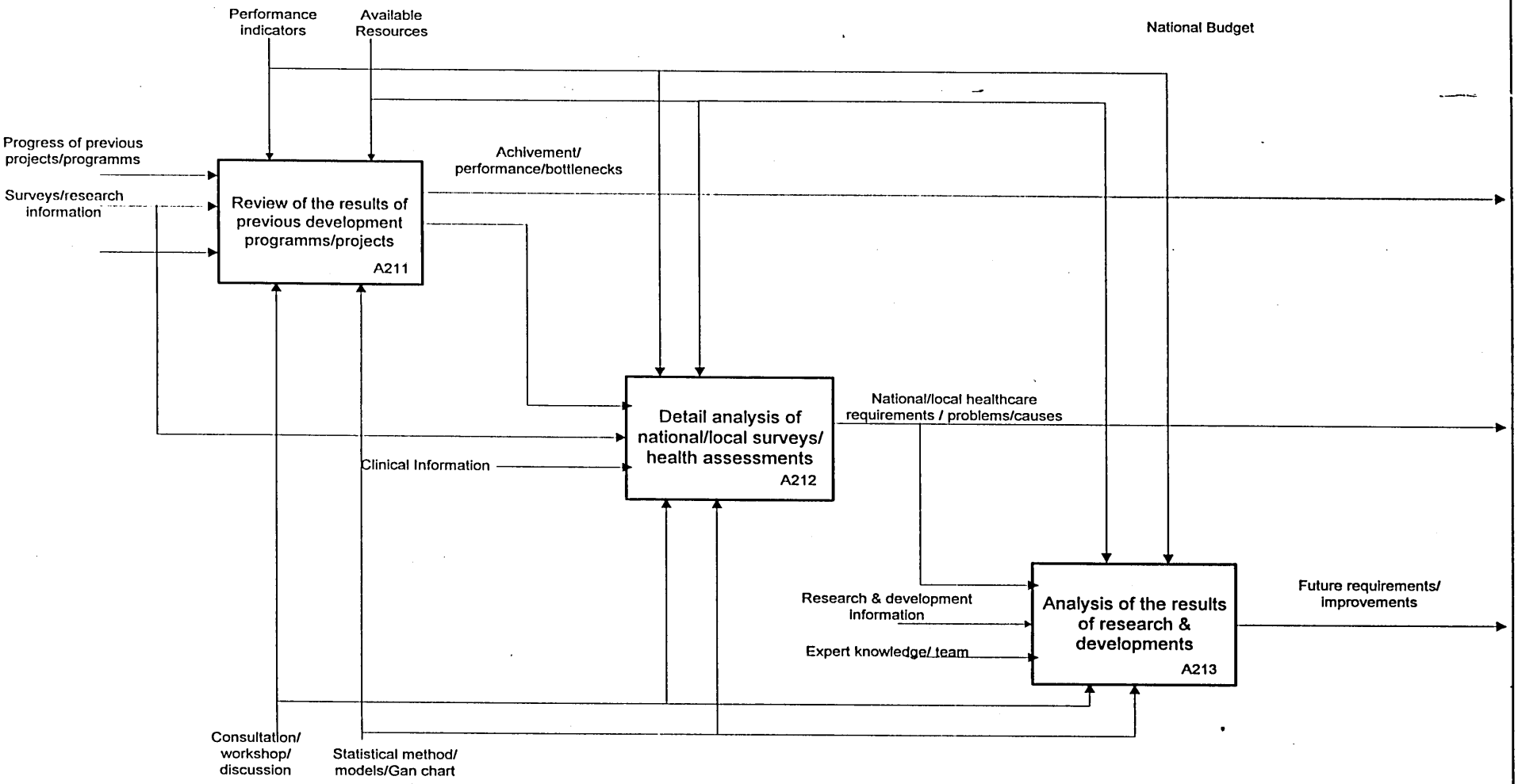


Diagram 3 : A 21: Review of Previous Policies/Programmes/Projects

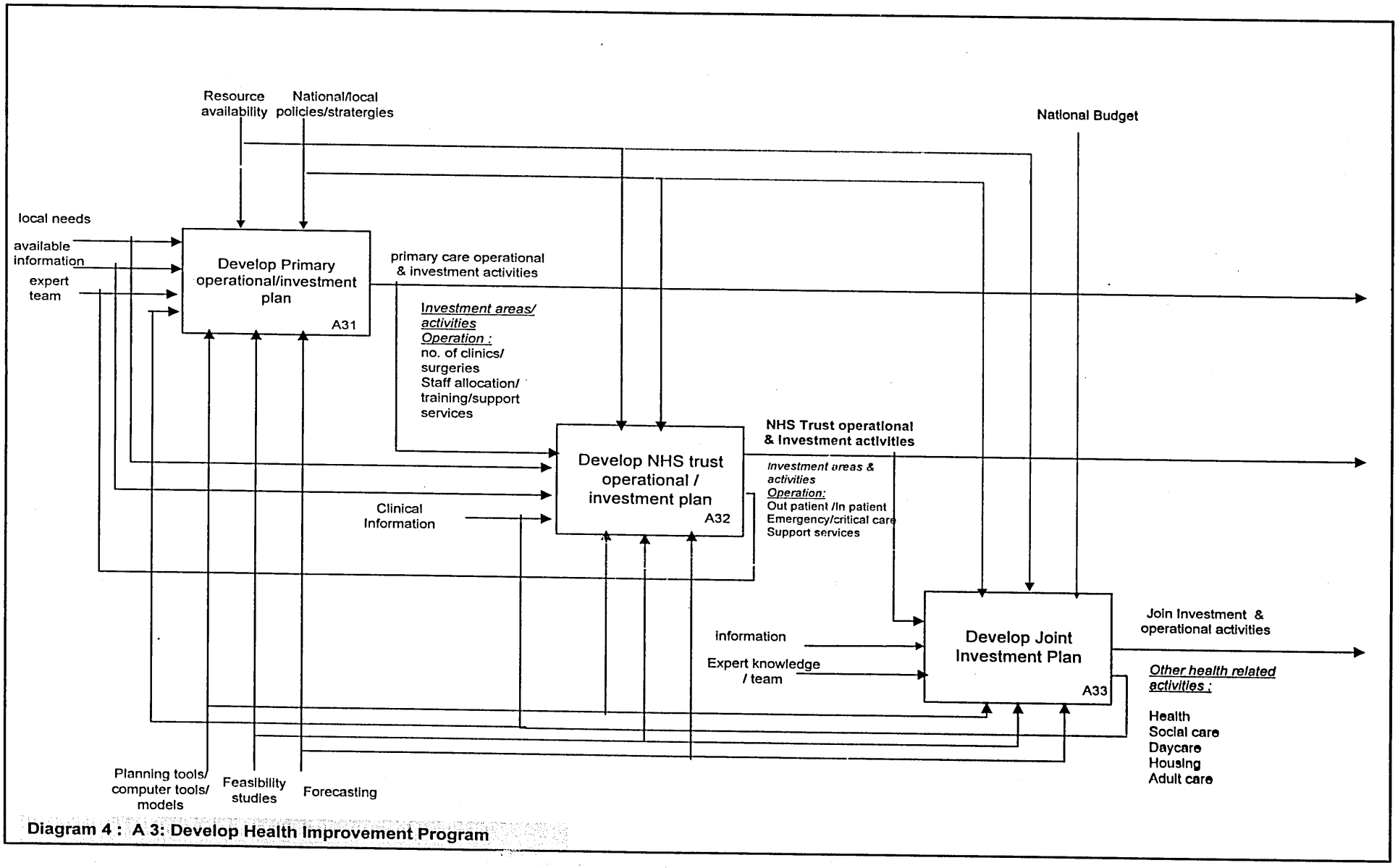


Diagram 4 : A 3: Develop Health Improvement Program

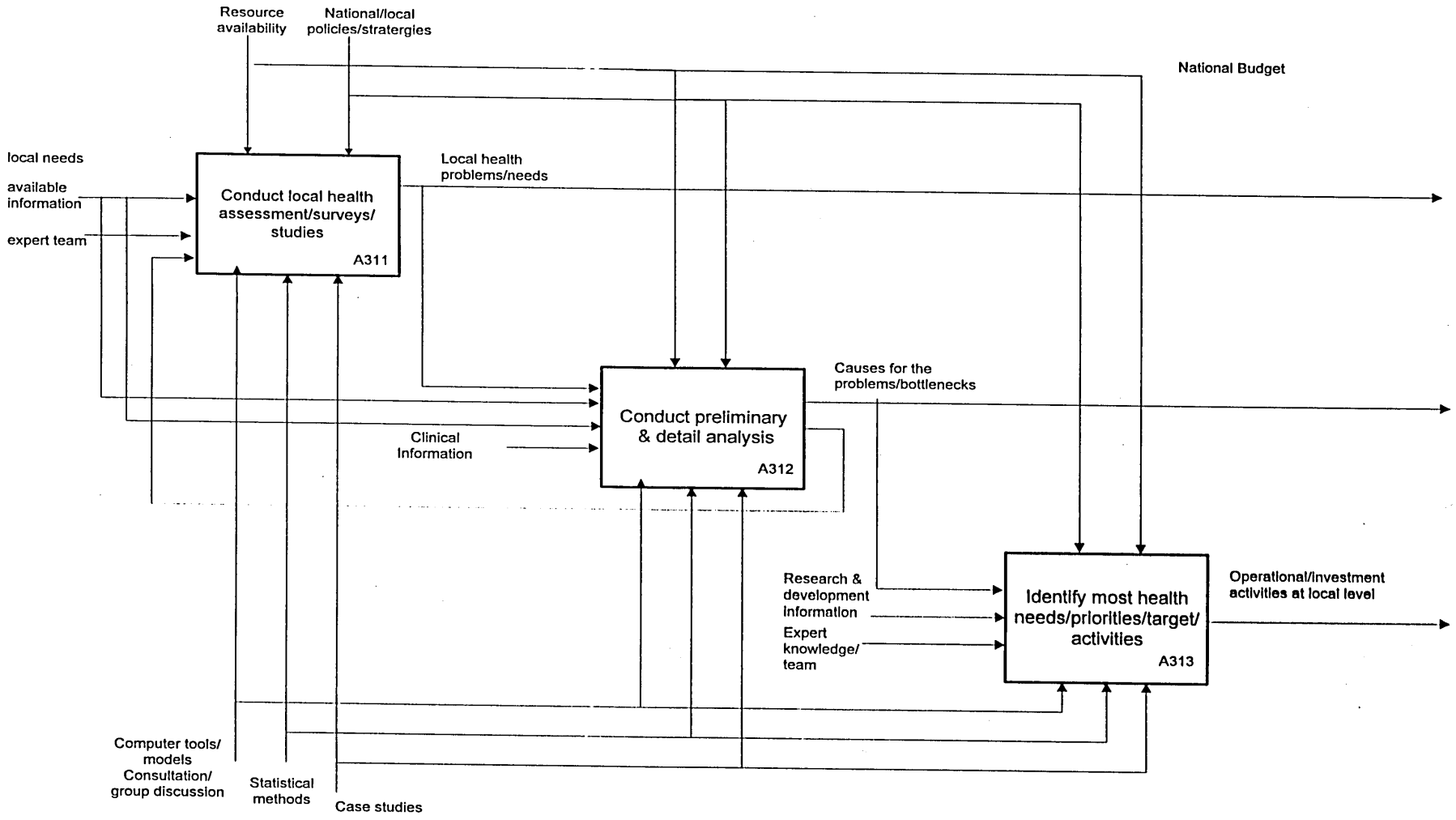


Diagram 5 : A 31 : Develop Primary Care Investment Plan

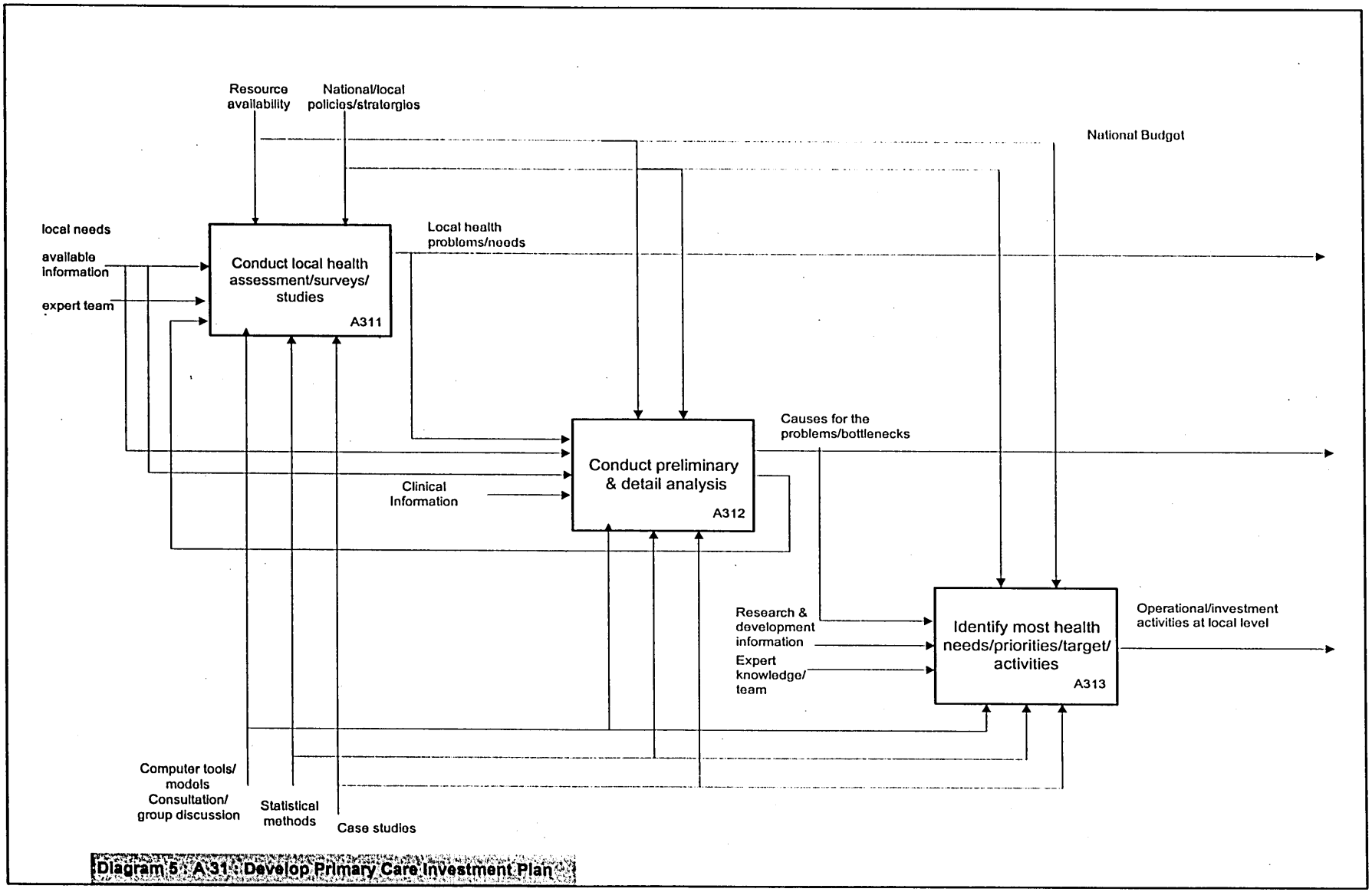


Diagram 5 : A 31 : Develop Primary Care Investment Plan

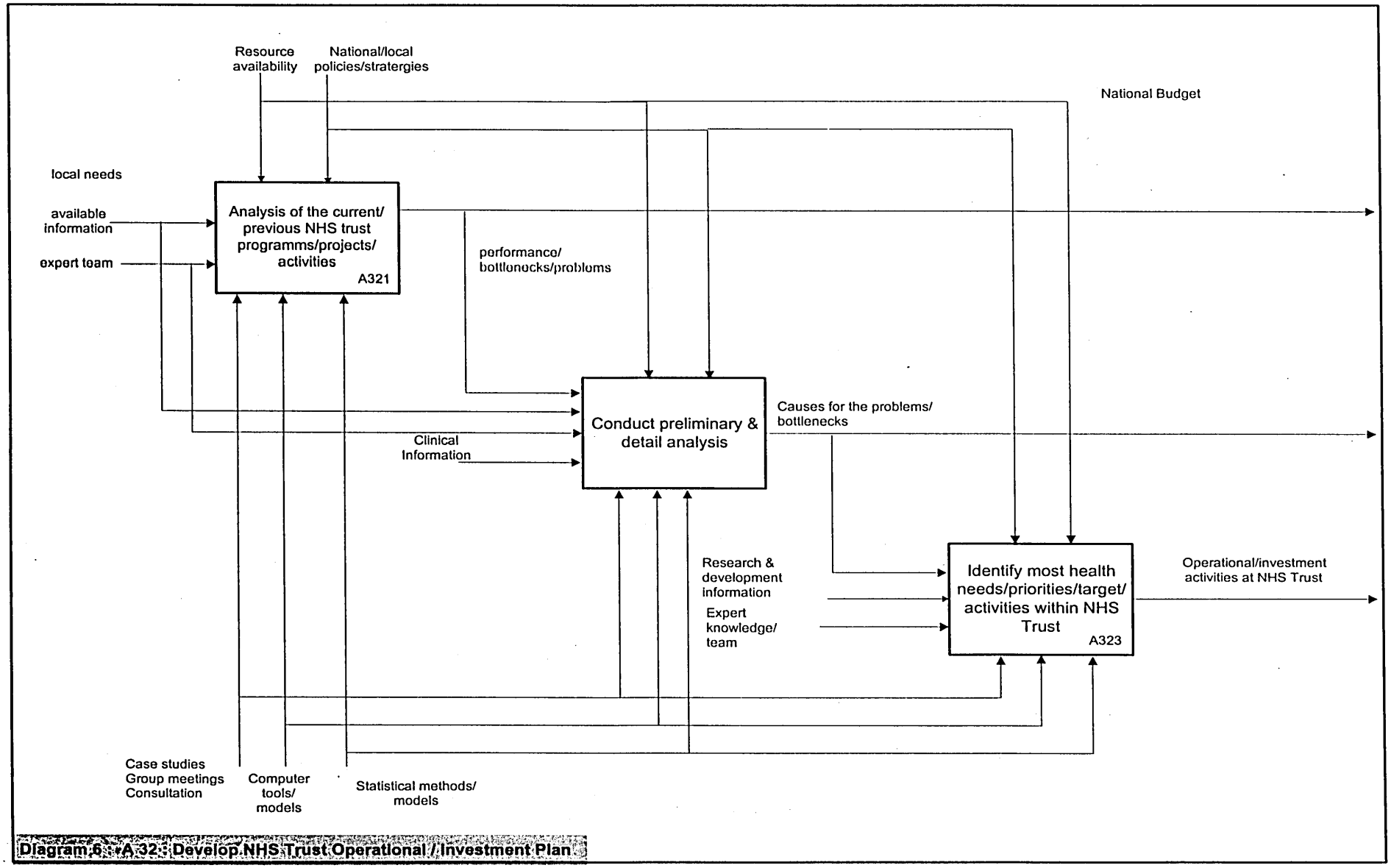


Diagram 6 : A 32 : Develop NHS Trust Operational / Investment Plan

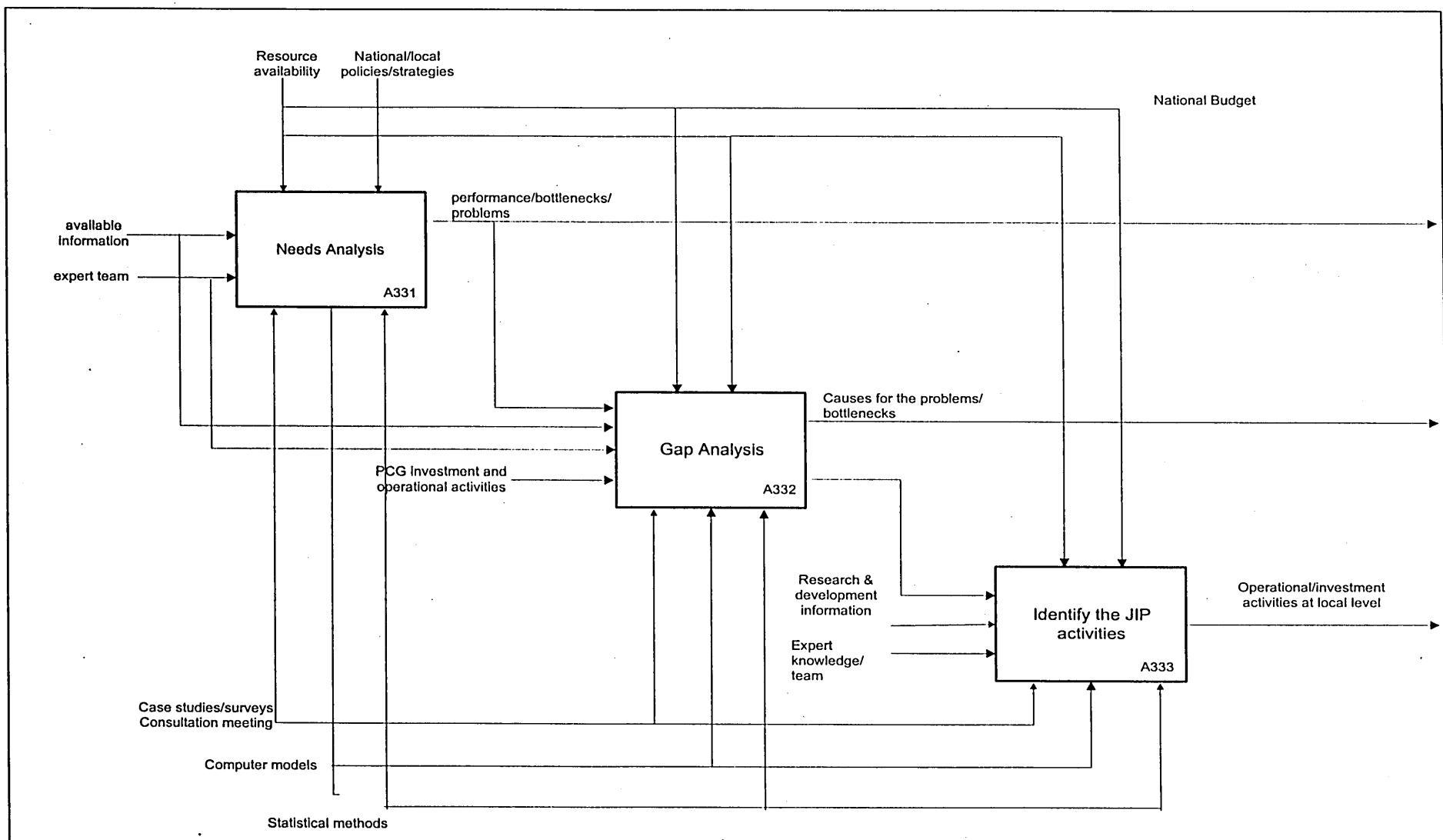


Diagram 7 : A 33 : Develop Join Investment Plan

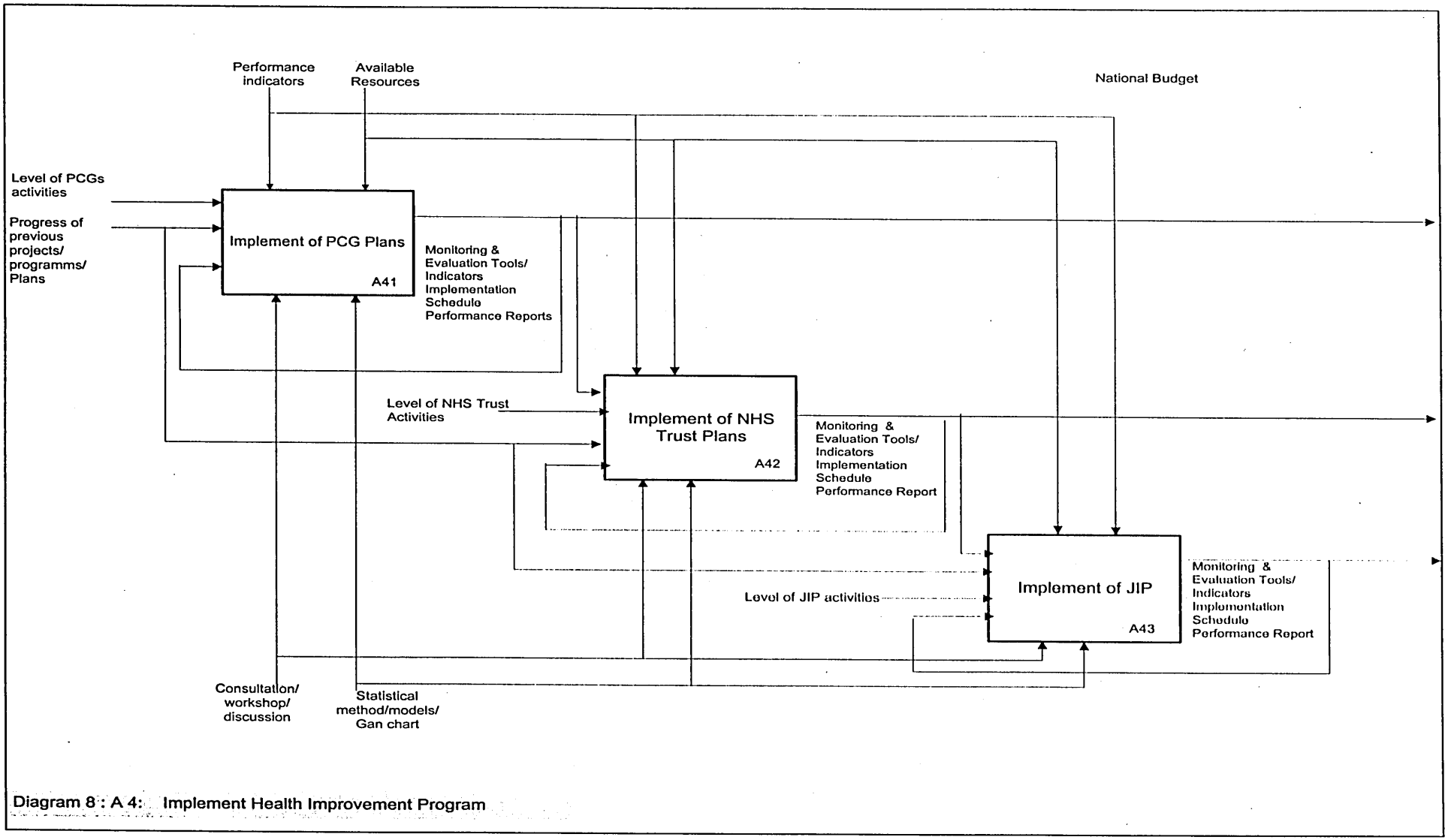


Diagram 8 : A 4: Implement Health Improvement Program

5.6.3 Summary of the analysis of Health Service Planning Process, England

IDEF Box No.	Title of the Box	Tools used					Opportunities for Simulation tool
		Consultation Workshop Meetings discussions	Gantt chart Worksheets Computer model	Statistical Methods/ mathematical models	Quantification evaluation methods	Computer Simulation	
A1	**Develop Healthcare resource & structure**	**H**	**M**	**H**	**M**	**L**	**L**
A2	**Develop Healthcare strategies**						
A21	Review of Previous policies/Programs/Projects						
A211	Review of the results of previous development programs/projects	H	M	M	H	M	L
A212	Detail analysis of national/local surveys/health assessments	H	H	H	H	N	L
A213	Analysis of the results of research & developments	H	M	H	H	L	M
A22	Consultation & draft strategies development	H	M	M	L	L	L
A23	Develop final strategies	H	M	M	L	N	L
A3	**Develop Health Improvement Program**						
A31	Develop Primary care operational/investment plan						
A311	Conduct local health assessments/surveys/studies	H	L	L	H	M	H
A312	Conduct preliminary & detail analysis	H	M	H	H	M	M
A313	Identify most health needs/priorities/targets/activities	H	M	M	M	L	L

IDEF Box No.	Title of the Box	Tools use					Opportunities for Simulation tool
		Consultation Workshop Meetings discussions	Gantt chart Worksheets/ Computer model	Statistical Methods/ mathematical models	Quantification evaluation methods	Computer Simulation	
A32	Develop NHS trust operational/investment plan						
A321	Analysis of the current previous NHS trust programmes /projects/activities	H	M	H	H	M	H
A322	Conduct preliminary & detail analysis	H	M	M	H	M	M
A323	Identify most health needs/priorities/targets/activities at NHS Trust	H	M	M	M	M	H
A331	Need Analysis	H	M	M	M	L	M
A332	Gap Analysis	H	M	M	M	L	M
A333	Identify the JIP activities	H	M	L	L	L	L
A4	**Implement Health Improvement Program**						
A41	Implementation of PCG Plans	H	H	H	M	M	H
A42	Implement of NHS Trust Plans	H	H	H	M	H	H
A43	Implement of JIP	H	H	H	M	L	H

Current Usage	
Criteria	Key
High	H
Medium	M
Low	L
None	N

Opportunity for applying simulation	
Criteria	Key
High	H
Medium	M
Low	L
None	N

Table 06 : Summary of the National Health Service Planning Process, England

5.7 Discussion :

It is clear that use of computer simulation technology at national level healthcare planning process is very poor. During the past four-decade, very few applications were reported in this area. According to charles,(1999), almost all of the healthcare simulation applications developed during the last four decades were used to analyse wide variety of healthcare delivery systems at local level. Most of the local level healthcare simulation applications also develop to analysis patient treatment process and provider operating policies, still there are lot of opportunities for areas of support services and capital expenditure requirement at local level healthcare planning process.

Identifying opportunities for computer simulation studies at the national level of healthcare planning is very rare. So simulation technology should be promoted at local levels and that will be enable to evaluate propose national policies and strategies at local level.

Next chapter (chapter 6) is based on the development of specifications and prototypes for healthcare oriented simulation templates environment. First, it discusses the five areas where simulation tools has been mostly used in healthcare industry and analyses each area according to the structure and job process. Then it identifies the possible processes for healthcare specific simulation templates and developed specifications and prototypes for them. Finally, it discusses the advantages of using templates for healthcare modelling.

Chapter 6

DEVELOPMENT OF SPECIFICATIONS AND PROTOTYPES FOR HEALTHCARE ORIENTED SIMULATION TEMPLATES

6.1 Introduction

Although computer simulation has been used for more than two-decades in healthcare sector, recent studies have shown that it has not yet become a key technology in healthcare planning and management (Charle, 1999 and James, et al., 1994). Through an extensive survey of the literature and the discussions with both simulation practitioners and healthcare managers, it has been identified that lack of healthcare specific simulation environment is one of the major problems for the above drawback. Almost all of the available simulation software and languages originally developed to handle the manufacturing environment and does not provide enough facility to handle healthcare issues. It is also difficult for healthcare managers to understand the content and algorithms of these simulation tools.

The main aim of this chapter is to develop specifications and prototype templates for healthcare oriented simulation environment, which will enable the healthcare managers and practitioners to develop models quickly and efficiently.

This chapter discusses the development process of specifications and prototype templates for identified healthcare areas and goes on to highlight the benefits of healthcare oriented simulation templates. During the development specifications and prototype templates, ARENA simulation package was used.

6.2 Modelling and simulation with ARENA

ARENA is a SIMAN/Cinema based modelling / animation system, developed by Systems Modelling Co-operation and its provides a complete simulation environment that support all basic steps in a simulation study. The ARENA system includes integrated support for input data analysis, model building, interactive execution, animation, and output analysis. ARENA is a graphical modelling/animation system that is based on concepts from object-oriented programming and its offer a high level of modelling flexibility across a wide range of problem domains. It is very simple to learn and easy to use. One of the advantage of ARENA is it allows user to create new templates using it standard templates library (Michael, et at., 1994).

6.3 Development Process:

Based on literature survey, case studies and group meetings with healthcare managers, the simulation tools were found to be mostly used in the following five areas of the healthcare industry.

Areas :

- Hospital Pharmacy
- Emergency section/ department
- Outpatient clinic
- X-ray department
- Maternity process

During the development of specifications and prototype templates for the above areas, following steps were followed:

Step 1 : Analysis of the work flow through out the area with more details

Discuss and analyse the work flow through out the area using flow chart diagram. Also identify details of the jobs, processes and resources involved at each stage and input data to build simulation model.

Step 2 : Developing Specification and prototype template

Identify suitable processes for simulation template environment in each area and develop prototypes and specifications for them.

This chapter discusses the development of specifications and prototype templates for hospital pharmacy environment only. The development of specifications and prototype templates for rest of the areas are given in the Appendix C.

6.4 Area 1: Pharmacy of a Hospital

Pharmacy of a hospital plays a vital role in the hospital environment, providing drugs for in-patient, outpatient and emergency department, etc. Most of the time, it has to deliver the drug orders with least possible delay and zero error.

6.4.1 Step 1 : Analysis of the work flow through out the Hospital Pharmacy

Normally, there are three different types of orders are processed in the pharmacy. They are emergency orders, regular orders and outdoor orders. Always it gives first priority for emergency orders.

6.4.1.1 Emergency order:

All of the pharmacies give first priority for emergency orders and it interrupts the work of the pharmacist, who does all that is necessary to complete the order and ensure that it leaves the pharmacy without any delay. An emergency order does not follow all steps in the pharmacy workflow path. It passes checking for IV drugs and order filling steps only (figure 12).

6.4.1.2 Regular order:

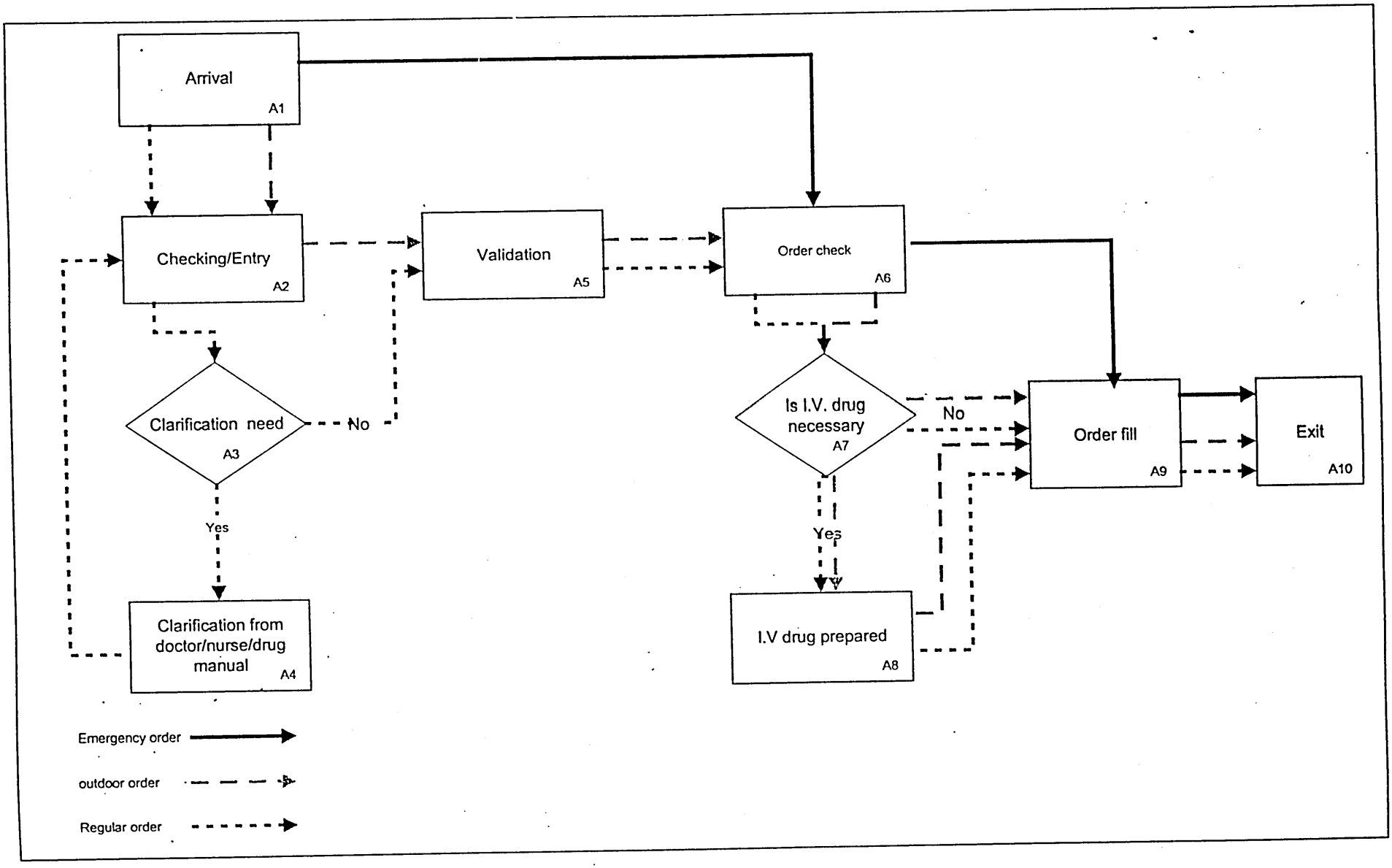
The regular order has a more predictable flow path through the pharmacy. The figure 12 indicates how a regular order moves through the pharmacy. When order arrives at pharmacy, administrative staff and order technician carries out order entry and checking process. During the checking process, technician identified actions need to be done on orders. Some regular orders are not clear, and so the technician needs to call up doctor/nurse to obtain clarification. In addition, for some orders, it may necessary to read manuals to check whether all drugs ordered for a patient are permissible. When the order is clear at this point, then it has to go for validation process. At most of the pharmacies, pharmacist is responsible for order validation. During the validation process, pharmacist checks order details clearly and validate them. After the validation process, orders have to move to the filling section. Before filling the orders, pharmacist check whether the order require preparation of intra venous drug (IV drugs) or not. Normally, order technician is responsible for preparation of IV drugs and order-filling process except in the case of emergency orders.

6.4.1.3 Outdoor orders:

Usually out door orders come from out patient clinic or out door doctors and it has to follow the same steps as regular orders except for the clarification process.

Figure 12 presents the flow of orders through the pharmacy.

Figure 12: Orders flow through the Pharmacy:



6.4.1.4 Detail analysis of each steps of the above order flow

Jobs	Process	Resource	Input	Data source
Arrival				
Emergency Order	Arrival	-	First creation Time between	
Regular Order	Arrival	-	First creation Time between	
Outdoor order	Arrival	-	First creation Time between	
Order Entry				
Regular Order	Order entry/checking	Pharmacist/technician/ admin staff	Entry/checking times	
Outdoor order	Order entry/ checking	Pharmacist/technician/ admin staff	Entry/checking times	
Clarification				
Regular Order	Clarification (from doctor/nurse or drug manual)	Pharmacist	Clarification time	
Validation				
Regular Order	validation	Pharmacist	Validation time	
Outdoor order	validation	Pharmacist	Validation time	
Order check				
Emergency Order	checking	Pharmacist	Checking time	
Regular Order	checking	Pharmacist	Checking time	
Outdoor order	checking	Pharmacist	Checking time	
I.V drug prepare				
Regular Order	I.V drug preparation	Pharmacist	Preparation time	
Outdoor order	I.V drug preparation	Pharmacist	Preparation time	
Order filled				
Emergency Order	Order filling	Technician	Order filling time	
Regular Order	Order filling	Technician	Order filling time	
Outdoor order	Order filling	Technician	Order filling time	

Table 7 : Details of order flow

6.4.2 Step 2 : Developing Specifications and prototype templates for Hospital Pharmacy

6.4.2.1 Possible processes for sample templates.

Considering orders flow and all the steps involved in pharmacy model, following processes were identified for simulation template environments.

- Order-Assign
- Order Entry
- Order Validation
- Order Check
- IV-Drug
- Order Filling

The above processes play greater roles in the pharmacy environment and most of the time efficiency of pharmacy depends on them. Also they are independent of each other and also very common to any hospital pharmacy environments.

6.4.2.3 Prototype templates and specifications for the above processes

- **Order-Assign or Entity-Assign**

This process is useful to create different types of orders according to arrival probability. There is no need to seize any resources for this process and an order will be automatically created with input data pattern. Types of input data required for this template are probability chances of having different type of orders. This template panel is most common to other areas in hospital environment such as emergency department, X-ray department, Out patient clinic, etc and it can be used to create different type of entities or jobs to the workflow of simulation models.

- **Order Entry**

Major actives involved in this process are order checking, order clarification and order entry. Usually, order checking and clarification processes are done by technician or pharmacist and admin staff is doing order entry process. Types of data required for carrying out these processes are checking time, clarification time and order entry time for regular order and out door order. Emergency orders do not pass this process.

- **Order validation**

Validation of regular orders and out door orders are the activities involved in this process and senior pharmacist is responsible for doing these processes. Types of input data that required for these processes are order validation times for regular order and out door order.

- **Order check**

Activities involved in this process are checking of different orders for IV drugs preparation and other clarification by pharmacist. Input data required for these processes are checking times for emergency, out door and regular orders.

- **IV –Drug**

Major activities involved in this process are preparation of IV Drugs (Intra Venous Drugs) for different types of orders. Certain orders require additional time to prepare necessary drugs before going to filling stage. For regular and out door orders, preparation process is done by order technician and pharmacist will do preparation for emergency orders. Types of input data required for these processes are preparation times for above three different orders.

- **Order filling**

Major activities involved in this process are filling of different type orders. Order technician does filling for regular and out door orders and pharmacist is responsible for

filling the emergency orders. Input data required for these processes are filling times for above three different type orders.

Considering all above factors, following prototype templates have been developed for above processes, see following figures.

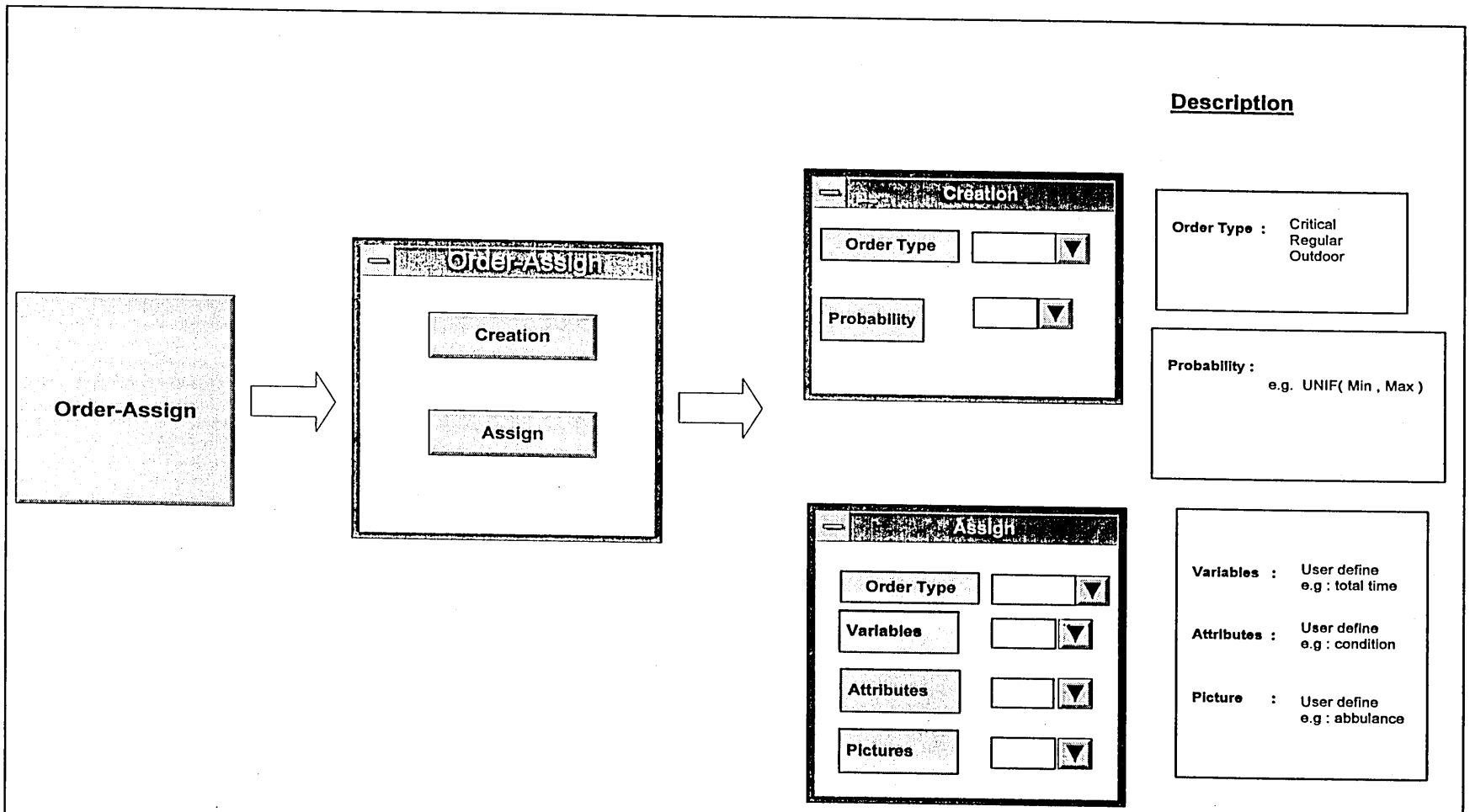
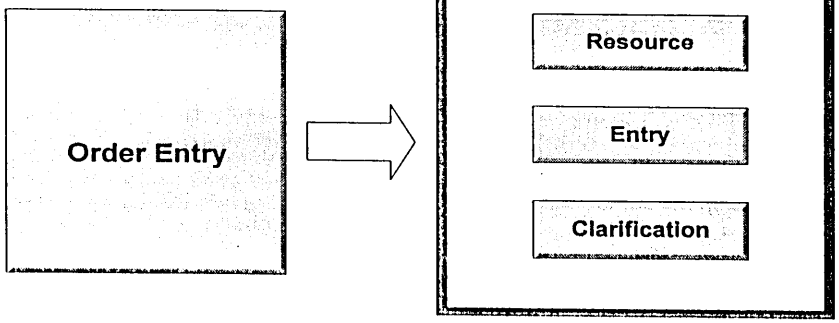
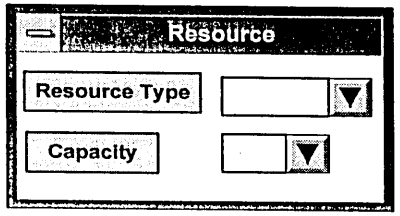
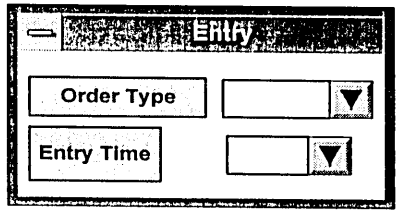
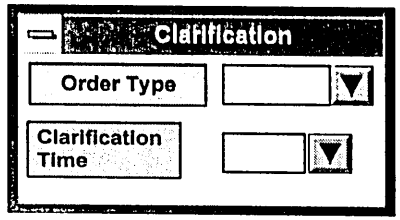


Figure 13 : Pharmacy : Template for Order Entry









Description

Resource : Type	Admin staff/Clerk Pharmacist

Order Type :	Critical Regular Outdoor

Figure 14 : Pharmacy : Template for Order Entry

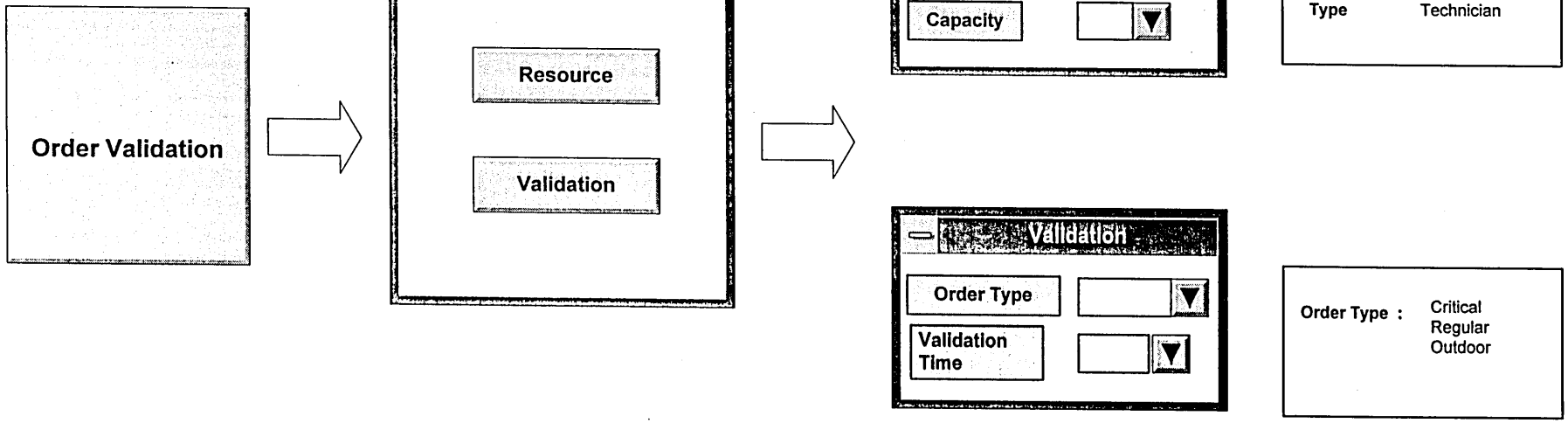


Figure 15 : Pharmacy : Template for Order Validation

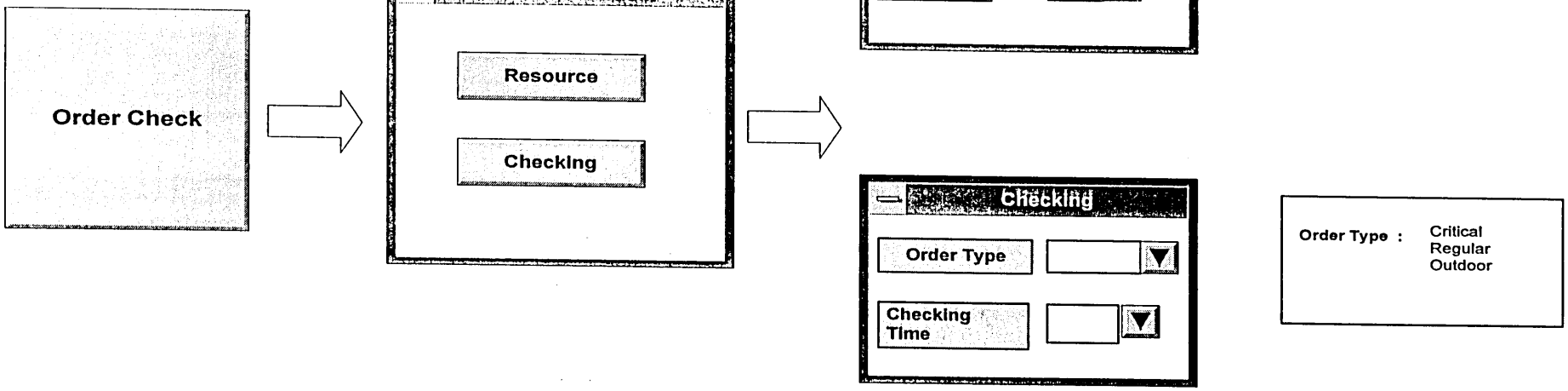


Figure 16 : Pharmacy : Template for Order Check

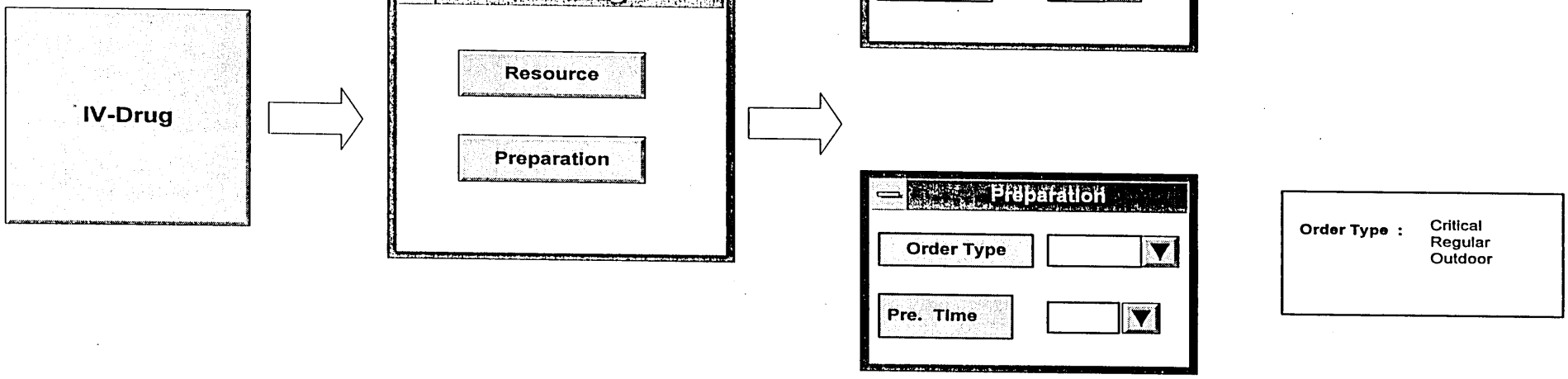


Figure 17 : Pharmacy : Template for IV-Drug

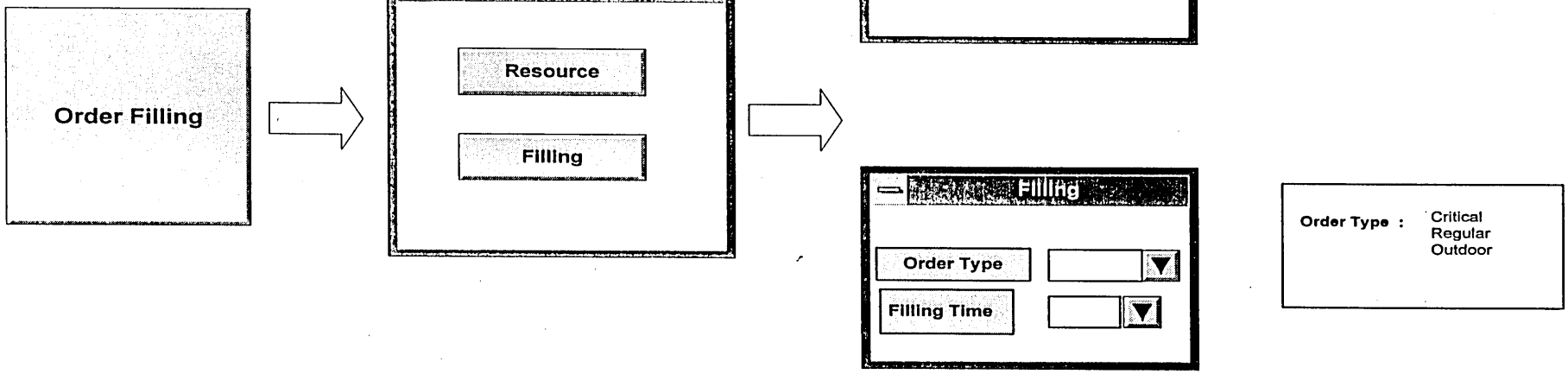


Figure 18 : Pharmacy : Template for Order Filling

6.5 Advantages of healthcare oriented simulation template

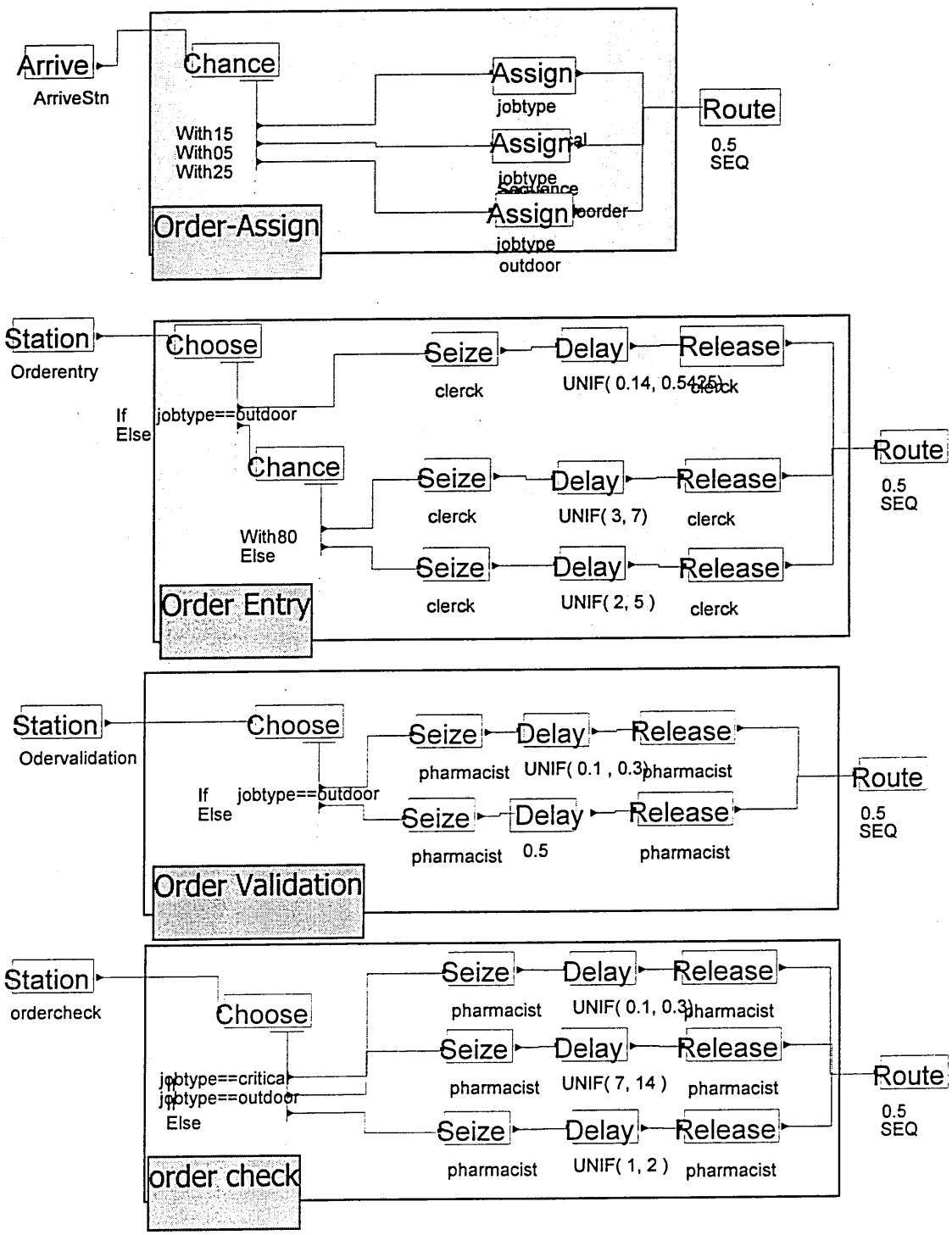
6.5.1 Accelerate model building process:

Most of the currently available simulation software and languages are specially designed to handle the manufacturing environment and does not provide enough facilities to handle unique healthcare issues. Also, it is difficult for healthcare managers to understand the content and algorithms of these simulation tools. They may have to follow several logical steps to handle the minor healthcare problems. Healthcare oriented simulation template environment is one of the solutions to overcome the above problems and it will accelerate the model building process reducing unnecessary logical algorithms / steps and the time spent for model development.

Example

Following examples show the differences between the healthcare template oriented simulation model and non-template model (see example **a** and **b**).

(a) Following example present the simulation model in non-healthcare template environment.



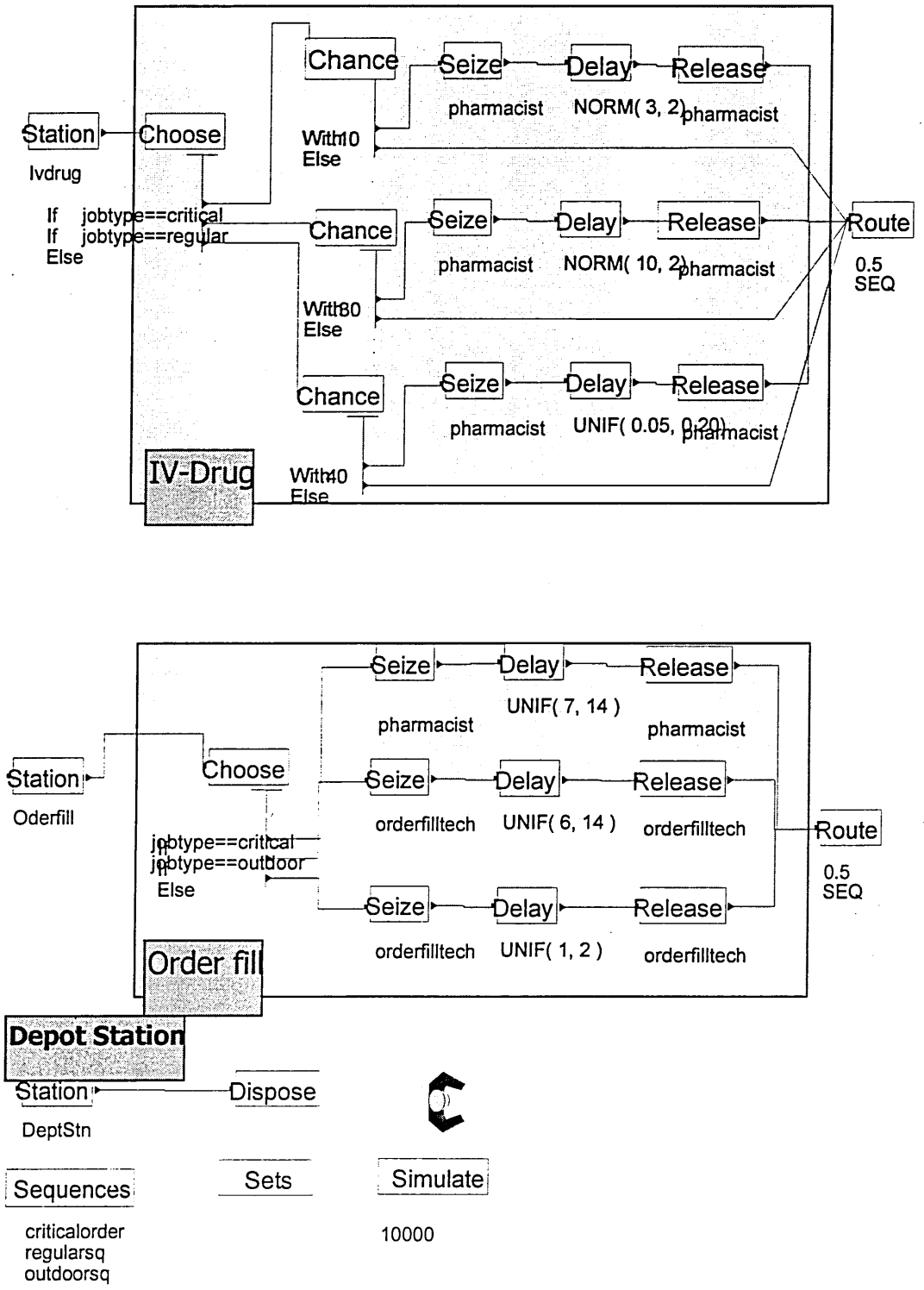


Figure 19 : Simulation model non-healthcare template environment

(b) This example shows the Pharmacy model with prototype templates.

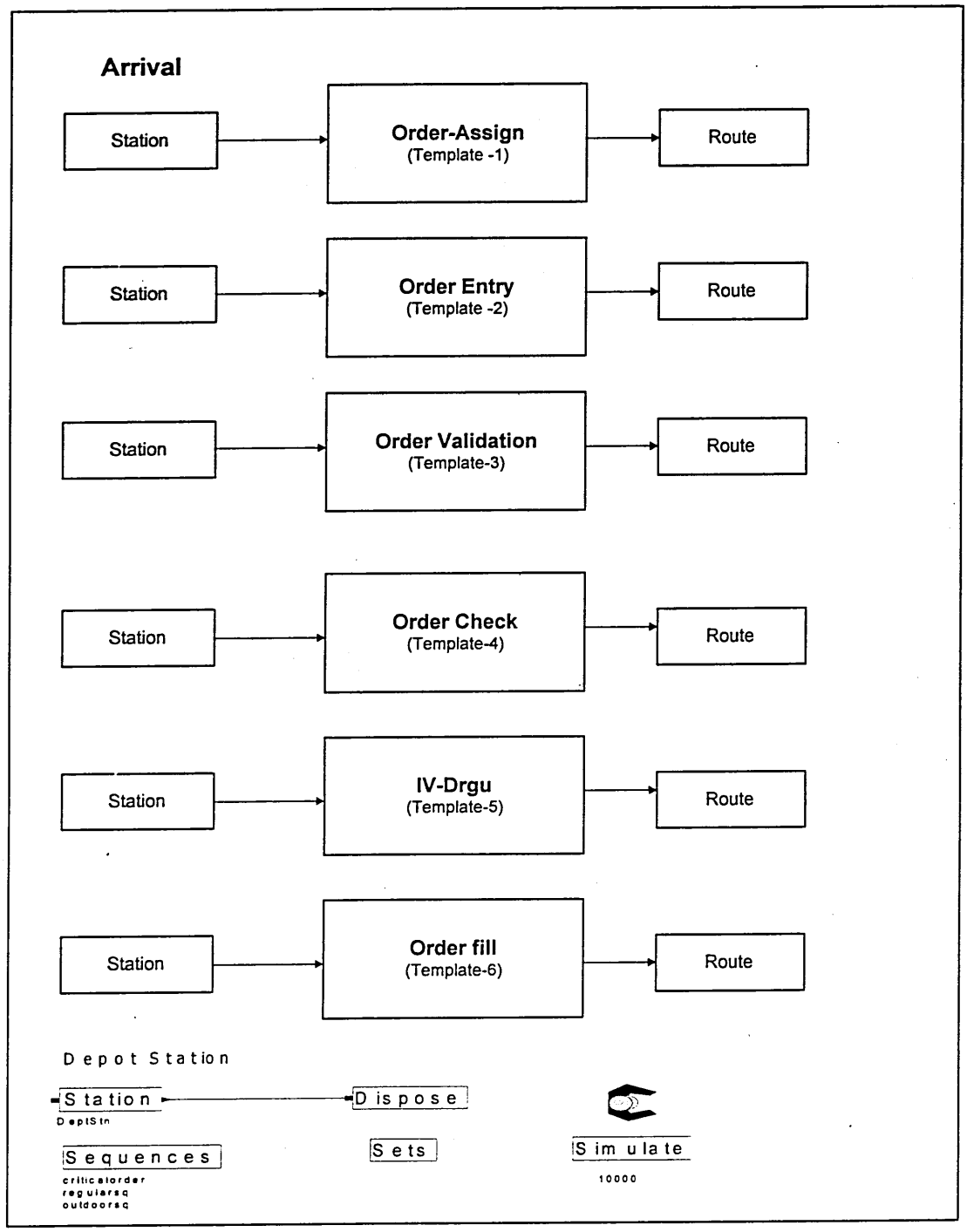


Figure 20 : Simulation model healthcare template environment

In example **a**, discusses the model, developed in non-healthcare templates environment and example **b**, discusses the model with propose healthcare oriented templates environment. Compare to model **a**, model **b** can provide same output using very few modelling steps(see output below). Also time spent to build model **b** is considerably short compare to model **a** and model **b** is very easy to understand for non modelling client like healthcare managers.

Example for same output

Model a output

Total Time in system by order type(All time in Minutes)	
Order type	**Average**
Regular order	32.25
Critical order	6.21
Outdoor order	11.5
Telephone call	0.70
Utilisation of resources (%)	
Pharmacists	52
Computer Technicians	91
Order Technicians	77

Model b output

Total Time in system by order type(All time in Minutes)	
Order type	**Average**
Regular order	32.25
Critical order	6.21
Outdoor order	11.5
Telephone call	0.70
Utilisation of resources (%)	
Pharmacists	52
Computer Technicians	91
Order Technicians	77

Model **a** and model **b** use same inputs and follow the same logical structure. Only the difference is model **b** is build with propose healthcare oriented templates environment, so model **a** and **b** provide same outputs.

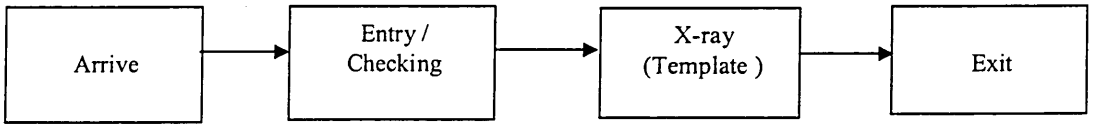
6.5.2 User Friendly Environment :

According to simulation modellers, most of the healthcare managers are not familiar with computer simulation tools and it is difficult for them to understand this technology. Therefore, it is not easy to present more logical and an algorithm steps models to them. The healthcare oriented simulation templates provide a better solution for the above problem by providing a user-friendly environment. Also, it does not involve complex algorithm steps and always looks like a program interface.

6.5.3 Easy Experimentation

Compared to existing healthcare simulation models, it is easy to do experiments like sensitivity analysis with healthcare oriented template models. With existing models, sometimes modellers have to change the model logic and alter steps to do such analysis. But in healthcare oriented template environment, modellers need to add one or more specific template panels only.

Examples :



The above diagram shows the basic model structure for X-ray department to mange the process of X-ray facility and it has only one X-ray processing room.

- **Sensitivity analysis:**

To check the performance of the above system with two or three X-ray rooms, the modellers can do experiments by adding another one or two x-ray template panels parallel to first x-ray panel as in figure 21.

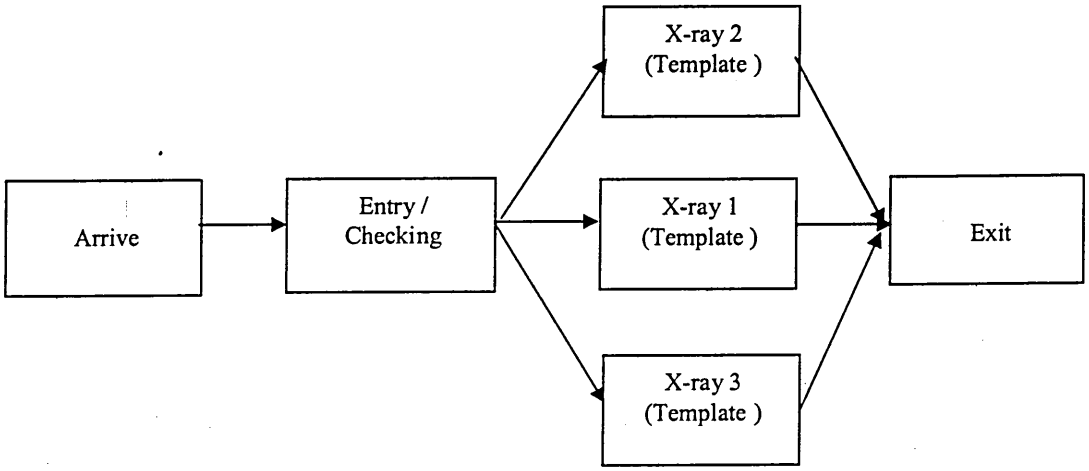


Figure 21 : Sensitivity analysis with X-ray templates

6.6 Comparison with MedModel

MedModel is a healthcare specific simulator package developed by Promodel Corporation. It was specially designed to be able to tailor to the needs of healthcare managers, engineers and clinicians (Steve, 1997).

MedModel provides simulation tools with a graphics library, which allows developers to produce a user interface. However according to some modellers (Moreno, et al., 1999), use of this software is not particularly popular due to several drawbacks such as model limitations, inflexibility and poor integrative capacity with other software applications.

With the Medmodel simulator package, modeller has to do programming and follow the logical steps common to Promodel software. Further it does not provide a user-

friendly environment for non-modelling clients like healthcare managers, administrators, etc.

A development of healthcare oriented simulation templates in ARENA system environment is one of the best ways to overcome the above difficulties. Compared to MedModel , it does not involve complex programming steps and always looks like a program interface. Also it can communicate with other software applications without any difficulty. Time spent to build a model using these templates are very short compare to that with MedModel and it also provide a user-friendly environment.

Unlike with MedModel, the healthcare templates developed with ARENA, can be repeatedly used to build future healthcare models.

6.7 Discussion

This chapter discuses the development of specifications and prototypes for healthcare oriented simulation environment. The development of above specifications and prototypes are limited to some selected healthcare areas such as hospital pharmacy, emergency department, maternity ward, etc. These areas were selected based on the popularity and demand but still there are lots of other areas in healthcare sectors that need to be considered. Unlike to manufacturing sector or other industries, there are no major differences in handling the jobs between two different institutes in same area in healthcare industry.

Example : Management of operations in pharmacies of two different hospitals,

- both handling same type of jobs like, emergency order, regular order , outdoor order, etc
- both gives first priority for emergency orders,
- both doing the same steps like checking/entry, validation and order filling.

Next chapter (chapter7) of this thesis make the conclusions and suggest areas that deserve further work.

Chapter 7

CONCLUSION AND FUTURE WORK

Conclusion

The thesis discussed the study of best practices for computer simulation in healthcare system and focused on development of a customised simulation environment for healthcare resource planning and management.

At the beginning of the thesis, present valuable information on the usage of simulation tools in healthcare industry and identified best practices and problems encountered during the healthcare modelling and simulation.

Then the study discussed the simulation model building process briefly and highlighted the issues involved in healthcare oriented simulation modelling. Useful suggestions were made to improve the model building process in healthcare sector. A Number of simulation models related to popular healthcare problems were demonstrated in detail

Also the study modelled the healthcare planning process using IDEF0 methodology in order to assess the current applications of computer simulation tools within the planning process. This investigation also identified further areas of applications of simulation in healthcare planning.

During the review of literature and the development of computer simulation applications in healthcare industry, it was identified that the development of healthcare specific simulation templates environment is one of the best ways to increase efficiency of the model building process in healthcare industry. Close co-operation of simulation modellers and healthcare managers was also identified as a key factor for success.

Contribution to the Knowledge:

The mains contributions from this study are :

- **Development of functional models**

This study was able to develop functional models for healthcare planning process based on England Healthcare Structure and provided valuable information on the entire healthcare planning process. These models were developed using IDEF0 methodology and they were also able to identify the areas where computer simulation technology is currently used and other opportunities for computer simulation technology in the healthcare sector.

- **Development of specifications and prototypes templates**

One of the most important outcomes of this research was the development of specifications and prototype templates for a customised simulation environment in health care planning. Number of prototype template panels and specifications are developed for selected range of healthcare problems. Also a few of real template (basic) panels for operation management of the hospital pharmacy were developed and experimented.
These template environments provide a better opportunity for healthcare managers and modellers to build models rapidly with least difficulty and it will undoubtedly help to increase the use of simulation technology in healthcare industry.

Future Work

- Healthcare is a highly complex system and it has several subsystems to carry out its functions. Thus there are lots of opportunities for computer simulation technology. Therefore research initiatives are needed to determine areas of healthcare system which has a potential to appl y computer simulation technolog y.

- It is necessary to build a set of reference models library for popular and in demand healthcare problems to convince healthcare managers of the benefits of simulation technology and arouse their interest.

- In this study, development of specifications and prototype templates were limited to five areas, but there are many other potential areas. Therefore further research needs to be done to identif y the other areas where healthcare templates can b e developed.

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APPENDIX A

INDIVIDUAL ANALYSIS OF HEALTHCARE ORIENTED SIMULATION APPLICATIONS

Application No 1. :

Title/Author/ Publish place/Year	:	A simulation model for evaluating personnel schedules in a hospital emergency department Tesham B., Edward Unger. In Proceedings of the 1996 Winter Simulation Conference, 1205-1209
Objective	:	to investigate various schedules for nurses, ER technician and doctors in order to reduce the average providing management with better insight in to the working of the ER and to determine how other factors affected the average length of stay of patients.
Problem investigated/ Model developed	:	Hospital Emergency Dept, model for Emergency Room (ER), evaluates various schedules for nurses, technicians and doctors.
Language / software	:	ARENA
Remarks	:	This paper describes an Arena simulation model of a particular hospital's emergency department. The model allow the simulation of process flow of 13 different types of patients, and is used to evaluate various feasible schedules for nurses, technicians and doctors. The main performance measure used in the evaluation process is the average length of stay of patients in the emergency dept. **Data Collection :** some of this data was collected through the use of group discussion with staff members and other data such as that associated with arrival rates for different types of patients was collected from ER logs and patient record **Validation :** The model was run on a pilot basis to perform first pass validation against actual data. The system performance measure monitored was total time spent by patients in ER, relative frequency distribution of length of stay of patient in the ER . One week activity of was compared against actual data from patient observation. **Experiment:** Experiment done using mix of patient type; process activities, including duration of those activities; demand for the ER; and schedules for nurses, technicians and doctors. (Louisville, Kentucky Hospital)

Application No 2. :

Title/Author/ Publish place/Year	:	Simulation of the Question Physician Network James R. Swisher., Brian Jun., Osman Balci., Sheldon H. Jacobson In Proceedings of the 1997 Winter Simulation Conference, 1146-1154.
Objective	:	to design the optimal patient physician encounter by maximising patient throughput and minimising cost per patient while still providing quality care.
Problem investigated/ Model developed	:	Operation of a Question clinic and Question Information Centre. Model includes a standard clinic layout, standard medical personnel and standard patient type.
Language / software	:	Orca computer, Incs object- oriented, domain independent visual simulation software.
Remarks	:	This paper examines the construction and implementation of a simulation model that supports the design and development of Question Physician Network. Model is built an object oriented visual manner utilising the Visual Simulation Environment(VSE). Patient throughput can be increased by altering scheduling and admission rules.(Baron and Averill 1973, Jun, Jacobson and Swisher 1977)

Application No 3. :

Title/Author/ Publish place/Year	:	A Generalised simulation system to support strategic resource planning in Healthcare Martin Pit . In Proceedings of the 1997 Winter Simulation Conference, 1155-.
Objective	:	to investigate the use of interactive simulation in strategic healthcare management. to develop a simulation system which could demonstrate support for these identified management needs.
Problem investigated/ Model developed	:	a simplified high level hospital model was developed to simulate the flow of patients through the different especially streams and wards of existing hospital in Halifax, UK
Language / software	:	Visual Basic WITNESS simulation software (ver 8)
Remarks	:	Planning Resource using Interactive Simulation Modelling (PRISM) designed for direct use by managers within the healthcare profession. This has been developed in liaison with health authorities in West Yorkshire, UK where a new hospital is currently planned. The results are validated against real healthcare data and the potentials of the system are evaluated within the strategic management process. This simulation users an array of demographic and healthcare data to generate representative daily caseloads of patients. The treatment pathway of each simulated patient is then modelled through the different specialities of care and across a series of treatment phases. **Design issues :** The level of complexity and interaction both within and between the specific institutions of the healthcare presented a particular challenge to any attempts to model and quantify the effects of likely changes. **Experiments:** Experiment with this model have focused on issues of resource and particularly the level of bed use under varying conditions, key questions concerned the impact of flexibility of bed provision, the effects of predicted changes in healthcare performance and changes due to demographic factors

Application No 4. :

Title/Author/ Publish place/Year	:	An on-line Simulation- Based Patient Scheduling System. Hans Manansang., Joseph A. Heim. WSC-1996
Objective	:	to demonstrate the concept and to address various problems to be faced in implementation of the patient scheduling system
Problem investigated/ Model developed	:	Simulation modelling approach for scheduling patient in medical clinics.
Language / software	:	Visual Basic, ARENA, ACCESS
Remarks	:	In this research, the application of on line simulation for patient scheduling decision support in a clinical environment is investigated. A prototype system was design and constructed to demonstrate the concepts and to address various problems to be faced in implementation of the system. The graphical user interface provides a means of entering and events schedule into the system. The database stores the value of individual such as arrival times of the patients, the diagnosis of treatment and the time patient leaves the system. The

simulation engine provides the simulation capability to examine and predict the behaviour of the system according to variable stored in the database.

The paper examines the co-ordination of multiple resource allocation and resource sharing dependencies among several closely related speciality clinics within the University of Washington.

Result: combination of qualitative professional skills and comprehensive planning tools can substantially improve the service and efficiency of the healthcare system.

Application No 5 :

Title/Author/ Publish place/Year	:	Design of Hospital Admission System Using Simulation Julie C. Lowery WSC-1996.
Objective	:	to design admission scheduling system which can control hospital occupancy
Problem investigated/ Model developed	:	Hospital simulation model. The model represents patient movement through multiple bed services based on actual patient flow patterns identified from each hospital data on patient admissions, discharges and transfers
Language / software	:	Simulation Language , GPSS/H
Remarks	:	This paper report on the initial phase of the research demonstrating the technical feasibility of developing a simulation model patient arrivals to and discharge from a hospital, which can be used to design the scheduling system.

Application No 6 :

Title/Author/ Publish place/Year	:	Birth of a new maternity process * William C. Johnson- Quality management Division., Miami Valley Hospital- Dayton, Ohio, USA WSC- 1998.
Objective	:	Optimising patient flow and building capacity for Berry Women's Health Pavilion by modelling. to determine optimal capacity and possible solution.
Problem investigated/ Model developed	:	maternity model - to represent the patient flow and census
Language / software	:	MedModel 3.0
Remarks	:	A computer model was developed to represent the patient flow and census. It also analysed the effect of differing patient types, increasing volumes, maternity unit configuration and policy changes. **Model Issues:** Simulation was used to identify improvements, which maximised room utilisation opportunities for process changes and optimal expansion opportunities. **Issues addressed included :** - room/bed utilisation, maternity capacity, maternity routing process logic, hypothetical effects of increasing patient volume, hypothetical effects of mandatory discharge time, hypothetical effects of an aggressive short stay option.

Application No 7 :

Title/Author/ Publish place/Year	:	Dynamic Simulation Modelling of ICU bed availability William Cahill., Marta Render Cincinnati VA Medical Centre , USA

WSC-1999

Objective	:	The main aim of this model is to evaluate the effects of the planned changes on access to the ICU
Problem investigated/ Model developed	:	The model of patient flow and bed utilisation of ICU of Cincinnati VA Medical Centre.
Language / software	:	ARENA
Remarks	:	This model analysed the flow of patients through the ICU, telemetry and medical floor beds under current bed allocation. The model was then use to evaluate the effects of the planned phased construction. It also evaluated the following other issues: - The number of patients discharge per month, - Utilisation of ICU beds and length of stay, - Utilisation of telemetry beds, - Utilisation of medicine floor beds, - Impact on overall length of stay of medical patients.

Application No 8 :

Title/Author/ Publish place/Year	:	Success stories in Simulation in Healthcare. * Catherine Drury Barnes, Micro Analysis & Design Inc. USA * Carson Benson- Freeman White Inc.- USA * Joaluin L. Quiason, University Hospital & Medical Centre at Stony Book, USA. * Deidra McGuines, Premier Inc., USA. WSC- 97
Objective	:	
Problem investigated/ Model developed	:	Describe the following models : 1. Pre-operation procedure 2. New Hospital design 3. Out patient design
Language / software	:	Lanner's Witness program was chosen as the modelling software. MS-Project, Auto-Cad
Remarks	:	This paper will describe the use of simulation in Pre-operation procedures, Space utilisation and out patient studies.

Pre-operation Procedures:

to be performed in planed out patient clinic, on the day prior to the surgery. The reduction of the patients overall time in the facility was another goal.

New Hospital design :

Simulation was used to test department design at the blue print stage to assist in ensuring that the facilities master plan would indeed address the business and operation issues effectively.

Outpatient Design :

Application No 9 :

Title/Author/ Publish place/Year	:	Assessing the impact of patient care policies using simulation analysis. Timothy W. Butler., Detroit, Michigan., * Gary R. Reeves,. Kirk R. Karwan and James R. Sweigart.

Journal of the Society for Healthcare Systems vol. 3 no. 3, 1992.

Objective	:	to represent the complex interaction in the patient placement process- beginning with patient arrivals and continuing through discharge.
Problem investigated/ Model developed	:	The simulation model of patient placement process
Language / software	:	Simscript 11.5
Remarks	:	The model reflects current and potential patient assignment policies at a major south-eastern General Hospital. This paper extends that work by examining a wide variety of policy modifications and the sensitivity of increments in policy change.
Application No 10	:	
Title/Author/ Publish place/Year	:	An Emergency Department Simulation Model used to evaluate alternative Nurse staffing and patient population scenarios Margaret A. Draeger., Management Engineering Bethesda Hospial Inc- USA. WSC- 1992
Objective	:	To develop models of Emergency Departments(ED) patient flow and staff workload that could be used on an ongoing basis to make decisions about ED staffing, scheduling, treatment area designation and general patient flow
Problem investigated/ Model developed	:	Simulation models of Bethesda Hospital's three Emergency Departments were developed.
Language / software	:	For model development GPSS/H, Simulation animation PROOF
Remarks	:	This paper describes the system model used to represent the ED, model validation techniques used, output of the model and animation of the model. In addition, uses of the model for experimentation with nurse staff scheduling and patient population re-routing are described.
Application No 11	:	
Title/Author/ Publish place/Year	:	Simulation of a Hospital's surgical suite and critical care Area Julie C. Lowery Great Lakesd Health Services Research and Development Field Program, Dept of Veterans Affairs Medical Center- USA WSC- 1992
Objective	:	to design and implement a simulation model of a large tertiary care community hospital's surgical suite and critical care area for the purpose of assisting hospital management in determining critical care bed requirements.
Problem investigated/ Model developed	:	The simulation model is designed to represent the arrival of patients to, and their flows through, nine different units in the study hospital: 1. surgical suite(OR), 2. post anaesthesia recovery unit(PARU), 3. surgical intensive care unit(SICU) 4. intermediate surgical care unit(ISCU) 5. coronary care unit(CCU) 6. intermediate coronary care unit 7. telemetry unit, 8. medical intensive care unit(MICU), 9. ventilator unit.
Language / software	:	GPSS/H
Remarks	:	

Application No 12 :

Title/Author/ Publish place/Year	:	The use of simulation to Evaluate Automated Equipment for a clinical processing laboratory. Gene C. Dankbar., Jane L. Shellum., Kevin E. Bennet Division of Systems and Procedures- Mayo Clinic, Rochester- USA WSC- 1992
Objective	:	to seek solution that would be : 1). Improve the service to the patients and physicians 2). Lower the cost of processing samples and 3). Lower the risk of infection to the employee
Problem investigated/ Model developed	:	Simulation models were developed to perform the evaluation. Each simulation model encompassed the activities that occurred within the processing laboratory. The model was structured in a modular design so changes in equipment or processing steps could be accomplished quickly
Language / software	:	SIMAN, Simulation language
Remarks	:	This paper describe the series of simulation models were created to evaluate several vendor proposals submitted for automation of the central processing laboratory at Mayo Clinic in Rochester, Minnesota. The goal of automating central processing are to deliver highly quality product to the appropriate testing laboratory at a lower cost, decrease turnaround time for test results, and reduce potential employee exposure to biohazards. Reason for why simulation : very few extensive applications of clinical laboratory automation exist, Operational data was not available.

Application No 13 :

Title/Author/ Publish place/Year	:	A simulation model for management of operations in the pharmacy of a hospital Arup K. Mukherjee, Simulation- February 1991
Objective	:	to provide hospital management with a versatile laboratory tool that will enable them to evacuate the effect of changes in policies and strategies on the performance of the pharmacy.
Problem investigated/ Model developed	:	A simulation model for a pharmacy, incorporating the major activities in relation to processing of regular orders, emergency orders and outdoor orders has been presented.
Language / software	:	SIMAN
Remarks	:	The primary emphasis in this report was to present a readily usable tool for investigating operations management strategies in the pharmacy of a hospital. This model has been based on what the author observed in the pharmacy of the University of Tennessee Hospital. Objectives of pharmacy management is to deliver the drugs orders with least possible delay and zero errors

Application No 14 :

Title/Author/ Publish place/Year	:	Using simulation to reduce length of stay in emergency Department Frank McGuire WSC-1994
Objective	:	to test alternatives and choose a solution to significantly reduce the length of stay for patients in the emergency department in Sunhealth Alliance Hospital.
Problem investig ated/ Model developed	:	Simulation model for Emergency Department
Language / software	:	MedModel
Remarks	:	The hospital had already been considering several possible ways to reduce patient wait times, however there was significant difference of opinion over the relative merits of the different courses of actions. The conflict opinion was one of the key reasons the hospital administration decided to use simulation. No other allows you to test alternatives and view the results on-screen as effectively as simulation.

Application No 15 :

Title/Author/ Publish place/Year	:	Determining the size of the Gastroenterology Division Expansion Using Simulation Michal Cono., Kathryn Dawson HIMS - 1993
Objective	:	to determine facility and staff requirements necessary to support a high quality gastroenterlogy operation. ** Gastroenterlogy(GL) - University of California at SanDiego Medical Centre
Problem investig ated/ Model developed	:	Simulation model for GI unit in UCSD medical centre. The model provided both Pro's and Con's of alternative enabling decision makers to understand the potential consequence of each selection.
Language / software	:	SimPLE-1 Programming language
Remarks	:	UCSD medical centre, GI division claim that the facility could no longer adequately serve the existing patient population and considered the reconfiguration and renovation of its facility to be high priority. The following method were developed in GI model : 1. Utilisation 2. Patient waiting time 3. Daily overtime 4. Time unable to accommodate patient 5. Case throughput 6. Time last case end.

Application No 16 :

Title/Author/ Publish place/Year	:	A simulation model of an X-ray facility Mark A. Coffin and Brenda L. Killingsworth- School of Business East Carolina University Greenville Gaddy Lassiter - Washinton Country Hospital, Plymouth James W. Kleckley-

Western Simulation Multi Conference on Simulation in Health Science and Services(SCS) 1993.

Objective	:	to identify the causes for the excursive waiting time in the X-ray facility and to investigate means of decreasing the patient time.
Problem investigated/ Model developed	:	Two simulation model : 1. to model the X-ray facility and evaluate proposed changes to the facility. 2. to model the external environment and evaluate potential changes on the demand for a hospital service.
Language / software	:	SLAMSYSTEM software by Corporation
Remarks	:	This paper provides a methodology for implementing a simulation model for X-ray facility management within the healthcare planning knowledge network proposed by Kleckley, Killingsworth and Kletke (1991). - covers the design of two segments of the network model: the hospital environment modelling system which address the overall service demand and the Health Services Analysis Knowledge Based System which address the efficient management of internal operations.

Application No 17 :

Title/Author/ Publish place/Year	:	Multi-Hospital Validation of a critical care simulation model Julie C. Lowery- Great Lakes Health Service Research and Development Field Program, Dept. of Veterans Affairs Medical Centre. WSC-1993.
Objective	:	to design and validate a general simulation model of a hospital's critical care units, such that with minor changes to the model's input.
Problem investigated/ Model developed	:	Multi-hospital critical care simulation model : the model can be used to represent the critical care area in a variety of different hospitals.
Language / software	:	GPSS/H
Remarks	:	The results from this research suggest that a general critical care model can be written which is validated for multi hospitals. The model can then be used to help determine critical care bed requirements. Validation in four departments of Veterans Affairs Medical Centre.

Application No 18 :

Title/Author/ Publish place/Year	:	Business process Reengineering of an outpatient clinic using simulation. Donald P. Huebner, Senior Management Engineer- St. Johan Hospital and Medical Centre. Lillian R. Miller, senior Management Engineer. St. Johan Hospital and Medical Centre. HIMS- 1996
Objective	:	Key objectives were to determine the capability to expand and change the clinics processes to provide better customer service.
Problem investigated/ Model developed	:	Simulation model for clinic St. Johan Hospital.
Language / software	:	MedModel
Remarks	:	Simulation was used to review the clinic's facility needs, highlight any bottlenecks in the current system and test the effectiveness of various reengineering process changes before implementation. Since several of the process changes required renovation of the facility. simulation provided justification for renovation. Process changes suggested by reengineering teams were evaluated by simulation analysis / facility design.

Application No 19 :

Title/Author/ Publish place/Year	:	Resource Allocation/ Capacity Planning using simulation in the GL laboratory. Carig Incorvia - management Engineer Jewish Hospital Healthcare Services. HIMSS-1995
Objective	:	to evaluate the operation of a GI lab to determine the most appropriate staff and equipment levels and process flow to increase patient throughput.
Problem investigated/ Model developed	:	Simulation model for GI lab- Resource planing/ staff planning to increase patient throughput.
Language / software	:	SIMAN iv
Remarks	:	The problem question to be answered here was defined as " what combination of equipment will be required to service and increase the outpatient load in the GI lab of 50%. After validation of model, six different simulation runs were made : 1. Validation 2. Increased patient load with no increased resources. 3. Increased patient load add one fully equipped procedure room, no additional staff. 4. Incr. patient load, add two full time staff(to staff a procedure room) maintain the nu.of procedure rooms at the current level(2). 5. Increased patient load, add two full time staff(to staff a procedure room) add one procedure room. 6. Further increase the patient load, keeping the additional staff and room as described in (5).

Application No 20 :

Title/Author/ Publish place/Year	:	Simulation Modelling of Prehospital Trauma Care Robert L. Wears ., Carles N. Winton WSC-1993
Objective	:	to provide method by which the effect of modifications to the system can be estimated. to allow prediction of the effect of policy changes on system performance and patient survival. Alternative policy analysis and trauma centre resource utilisation.
Problem investigated/ Model developed	:	Simulation model of prehospital trauma care system.
Language / software	:	SIMSCRIPT ii.5
Remarks	:	Prehospital emergency care systems are complex and do not respond predictably to changes in management. A combined discrete-continuous simulation model focusing on trauma care was designed and implemented in SIMSCRIPT ii.5 to allow prediction of the effect of policy changes on system performance and patient survival. This project focuses more on clinical issues that are frequently modified dynamically by changing clinical and administrative policies. This model was designed to estimate the effects of changes in : a). Triage criteria that determine the centre to which a patient should be routed; b). Criteria for helicopter transportation's Vs ground transportation c). Divert policy (the circumstances and length of time during which a hospital may divert incoming cases to another facility). These effects will be measured from two perspectives : from the point of view of the system(no. of patient received , % utilisation etc) and

from the point of view of patient(length of time until definitive care, changes in servi probability)

Application No 21 :

Title/Author/ Publish place/Year	:	Emergency Department Simulation and Determination of optimal Attending Physician staffing schedules. Mannuel D. Rosetti, Gregory F. Trzcinski.., Scott A .Syverud. WSC- 1999
Objective	:	to develop an understanding of system performance relative to various attending physician staffing schedules.
Problem investig ated/ Model developed	:	Simulation models of Emergency department at the University of Virginia Medical Centre.
Language / software	:	Arena 3.0, simulation software.
Remarks	:	This paper discus the use of computer simulation to test alternative ED attending physician-staffing schedules and to analyse the corresponding impacts on patient throughput and resource utilisation. Its also be used to help identify process inefficiencies and to evaluate the effects of staffing , layout, resource and patient flow changes on system performance.

Application No 22 :

Title/Author/ Publish place/Year	:	Hospital Delivery System Comparison via simulation. Mannual D. Rossetti, 2000, Industrial Engineering Conference. (This result are based Un iversity of Virginia Health Science Centre.)
Objective	:	to assess the technical performance measures in the alternative systems. Out put analysis: Five factors were recognised under system consideration 1. speed of robots or couriers, 2. person arrival rate 3. delivery item arrival rate, 4. elevator availability, 5. robot availability.
Problem investig ated/ Model developed	:	Two computer simulation models were developed and the alternative solutions were compared in terms of technical and economic performance. Delivery System - simulation models: 1. model for the robotic 2. for the human based delivery system.
Language / software	:	MODSIM III, General purpose modular block structured high level programming language. direct support for object oriented programming and discrete event simulation
Remarks	:	This paper focuses on clinical laboratory and pharmacy deliveries within middle to large size hospitals in order to evaluate whether or not a fleet of mobile roboats can replace a tradition al human-based delivery system. The final results of this research enable a better understanding of the delivery and transportation requirements of middle to large size hospitals and how a fleet of mobile robots can meet these requirements.

Possible areas for further studies:

Analysis of robot interaction with nursing staff and analysis of a robotic system used in conjunction with a pneumatic tube system.

Application No 23	:	
Title/Author/ Publish place/Year	:	Simulation of Robotic Courier Deliveries in Hospital Distribution Services. Mannual D. Rossetti., Robin A. Felder, Director. Am ith Kumar Journal of Healthcare Management Science, 2000.
Objective	:	to illustrate the use of simulation modelling and analysis within a healthcare delivery system and to develop an understanding of the use of robotic couriers within a hospital environment. In this simulation based case study, the university of Virginia Health Sciences Center's (UVA-HSC) clinical laboratory and pharmacy delivery processes are used as an example to examine the use of robotic couriers within a hospital facility.
Problem investigated/ Model developed	:	4 simulation models were developed. 1st model describes the system as it currently operates using three human couriers. 2nd and 3rd models describe the operation of the system with robotic couriers serving as the primary delivery mechanism for the independent operation of clinical laboratory and pharmaceutical deliveries. 4th model combines the process associated with clinical laboratory and pharmaceutical deliveries and utilises robotic couriers as the primary delivery mechanism.
Language / software	:	ARENA
Remarks	:	This paper discusses the use of simulation modelling to analyse the cost, benefits and performance tradeoffs related to the installation and use of a fleet or robotic couries within hospital facilities. The results of this study enable a better understanding of the delivery and transportation requirements of hospitals. -it examine how a fleet of robotic couriers can meet the performance requirements of the system while maintaining cost efficiency.
Application No 24	:	
Title/Author/ Publish place/Year	:	Patient centred simulation tool for aiding in hospital management L. Moreno- , R.M. Aguilar., C.A Martin, J.D. Pineiro., J.I Estevez, J.F. Sigut., J.L. Sanchez., V.I. Jimenez. Simulation Practice and Theory- 373-393 1999
Objective	:	to obtain information about the hospital state through reports and graphs, to experiment with different control actions in order to know which is the correct one in a particular simulated simulation.
Problem investigated/ Model developed	:	A patient centred simulation model.
Language / software	:	Modsim, Modula 2 based language.- objected oriented block structured simulation language.

Remarks	:	Computer simulation is an efficient approach to the study of complex systems. This article has shown how to use it in the study of hospital management. Its also describes a management tool that supplies hospital administrator with information about hospital. * Different alternatives for the implementation were explored.
Application No 25	:	
Title/Author/ Publish place/Year	:	Using simulation to Craft a National Organ Transplantation Policy- A.Alan B. Pritsker., O. Patrick Daily., Kenneth D. Pritsker WSC-1996.
Objective	:	to develop the UNOS(United Network for Organ Sharing) liver allocation model(ULAM) for comparing proposed alternative allocation policies. a secondary objective was to create a model that could be used and updated at UNOS headquarters to meet the future needs of the transplantation community. (Division of Organ Transplantation, Dept of Health and Human Services - USA.)
Problem investigated/ Model developed	:	UNOS Liver Allocation Model(ULAM)
Language / software	:	Visual SLAM and AweSi
Remarks	:	This paper presents a description and analysis of what can be accomplished when simulations are used to support policy analysis and selection. Liver Allocation and Distribution policy is used as the vehicle for presenting specific details of how simulation can be used to support policy selection. UNOS, though its constituent-based committee structure, would be responsible for defining and evaluating alternative policies for transplantation allocation and distribution. The initial approach was to build, verify and validate a model with the transplantation community defining the performance measures, specifying the policy alternatives and then running the simulations to objectively evaluate the policy alternatives
Application No 26	:	
Title/Author/ Publish place/Year	:	Simulation of a hospital's theatre suite W.E. McAleer., J.A. Turner., D. Lismore., I.A Naqvi Journal of Management in Medicine , vo 9, No 5,995
Objective	:	To identify delays and restrictions in the system (due to resource imbalance) by using a Visual Interactive Simulation (VIS) model to explore the relationship between various throughput levels and resource allocations.
Problem investigated/ Model developed	:	Operating theatre suit model in large hospital , UK.
Language / software	:	Visual Interactive Simulation (VIS)
Remarks	:	This article describes a study of the main operating theatre suit in a large general hospital, consist of six operating theatres together with a common post-operative recovery unit. Visual Interactive Simulation (VIS) software was used due to two advantages: 1. It enables those who working the system being modelled to validate the model, 2. It provides a convenient means for the decision-makers to consider different ways of running the system. **Benefit :** The major benefit of this study was that it resulted in a much greater understanding of

the interconnected complexity of the overall system on the part of the various groups of staff involved.

Problem :

1. Management structure bureaucracy , during the decision making,
2. Lack of detail knowledge about the jargon used by the various groups,
3. Non-availability of data.

Application No 27 :

Title/Author/ Publish place/Year	:	Achieving hospital operating objectives in the light of patient preference Martha T. Ramirez. Valdiva., Thomas J. Crows International journal of Healthcare Quality Assurance Vol. 10 No. 5, 1997.
Objective	:	To enhance the response utilisation of the staff of outpatient clinics while meeting the mandated time liness standards. Place : outpatient treatment clinic at the Harry S Truman Memorial Veteran's Hospital in Columbia Missouri.
Problem investigated/ Model developed	:	Simulation model for outpatient clinic, Simulation Service Quality System (SSQS)
Language / software	:	SIMAN
Remarks	:	This research present the new methodology called the simulation service quality system (SSQS), developed to improve operating performance measures in the light of customer preference. Discrete-event simulation model was built and experiment with the system to ultimately arrive at recommended changes in hospital operating policies. Under this model, for the analysis of alternatives to achieve the timeliness customer service standard is developed based on the study of literature related to TQM, customer satisfaction and simulation in healthcare. After analysing different alternatives by means of a simulation model, the results suggest that in order to reduce the waiting time by a doctor, it is necessary to reduce the check-in time window. Main source of data for this model is based on workload report(listing of daily activities for each physician) and help desk information.

Application No 28 :

Title/Author/ Publish place/Year	:	An application of simulation to planning hospital pharmacy services. Bryony Dean., Ann Van Ackere., Steave Gallivan., Nick Barber Journal of Healthcare Management Science 2 (1999)
Objective	:	To investigate a simple problem and to assess the potential for simulation to aid decision making in hospital pharmacy management
Problem investigated/ Model developed	:	Simulation model of the drug distribution system.
Language / software	:	Extend (version 3.2
Remarks	:	This paper reports a pilot study of the use of simulation in planning hospital pharmacy services. Simulation model was used to investigate how changing the time of a ward pharmacist's visit could affect the mean time delay between the prescription of a non-stock drug and the arrival of that drug on the ward. **Results:**

The simulation results suggest that the time of day at which pharmacists visit their wards can have a major impact on delay times and that the relative benefit of different visit times is likely to vary between wards.

Major limitation :

Hospital outpatient not considered in this model

Application No 29 :

Title/Author/ Publish place/Year	:	Acute Coronary Artery Deficiency Treatment Process Tony Proctor Journal of Management i n Medicine, Vol. 11 No. 1, 1997.
Objective	:	To manage scare resou rce and maintains a level of services
Problem investig ated/ Model developed	:	Simulation model of Acute Coronary Artery Deficiency Treatment Process
Language / softw are	:	Dynametrics
Remarks	:	This article describes at a way of coming to grips with process problems that are presented with the aid of computer simulation of the stages that are involved in the treatment of cardiac problem s.

The main aim of this research is to answer the following question

How can more patients be treated during peak demand times? more beds, - more staff , - shorter waits

This model was build using the real example in the North of England Hospital and runs the simulation periods of two months time.

Problems & limitations of model:

The software used in this model does not allow the user to create variables and to monitor changes in the variables as the model progresses.

Application No 30 :

Title/Author/ Publish place/Year	:	Management of queues in Outpatient departments Limor Aharonson., Ray J. Paul., Anthony J. Hedley Journal of Management in Medicine, Vol. 10 No. 6, 199 6.
Objective	:	A practical approach to solving management problems in a rationally planned manner in this clinic and a modelling approaches is used to analyse queues, which are probably one of the most common management problems in outpatient clinics
Problem investig ated/ Model developed	:	Computer simulation model for management of queues in outpatient departm ents of Hong Kong government hospital.
Language / softw are	:	Med Model
Remarks	:	This study is to adopt an operations research approaches to the solution of queuing problems using computer simulation modelling.

The existing system was modelled and possible alternative management policies were tested on the model. Its demonstrates how choices can be tested by the model and only the preferred solution implemented.

The methods used in the study included a site appraisal and a time motion study. Simulation modelling techniques were used for experimentation and data analysis.

Problems

According to modeller, actu al experimentation in this study environment is very difficult, first because it requires changing patient and staff behaviour that can be a lengthy process, and second because it may interfere with clinic operation. Experimenting with several alternative management approaches would almost certainly be impossible in this setting.

APPENDIX B

Demonstration of Healthcare oriented simulation models

(Examples)

1. Model 1. Simulation Model for of Emergency Department (ED) of hospital

This example model describes the simulation process of a Emergency Department based on the University of Virginia Medical Centre in Charlottesville, Virginia .

1.1 Problem :

Emergency department is one of the busy places in hospital environment. Efficient allocation and utilisation of scare resources, reduce patient waiting and treating critical patients are few of the challenges facing by emergency department staff in their day to day work. Increased pressure from competition, healthcare reform, reimbursement difficulties, and rising healthcare cost are primarily responsible for the high level of interest in ED operating efficiency issues.

1.2 Model objective :

Main objective of this simulation model was to develop an understanding of system performance relative to various attending pattern of physician and other staff.

1.3 Background :

In this Emergency Department, there are a total of 34 beds for patient care divided in to four distinct care areas.

Area	Beds
Adult Care Wing	19
Chest Pain Centre	5
Paediatric Care Wing	6
Minor Emergency	4

- A patient enters the Emergency Department by one of three modes:

Mode	Type
Walk-in	Good patient
Ambulance	Major trauma
	Minor trauma
	Non Trauma

1.4 At the initial stage, staff allocated for each shift in the emergency Department as follows:

Resource Type	Capacity		
	Shift 1 (6am-3pm)	Shift 2 (3pm-9pm)	Shift 3 (9pm-6am)
Reg-clerks	3	2	1
Triage-Nurses	4	3	2
CPC-Nurses	4	3	2
CPC-Physicians	3	3	2
PED-Nurses	4	2	2
PED-Physicians	3	3	2
ME-Nurses	3	3	1
ADCW-Nurses	4	3	2
ADCW- Physicians	3	3	2
ED-Nurses	4	3	2
ED- Physicians	3	3	2
Trauma-Team	2	1	1

Table 1 : Staff Allocation at beginning

1.4 Flowing figure discus the flow of each patient types through the emergency department :

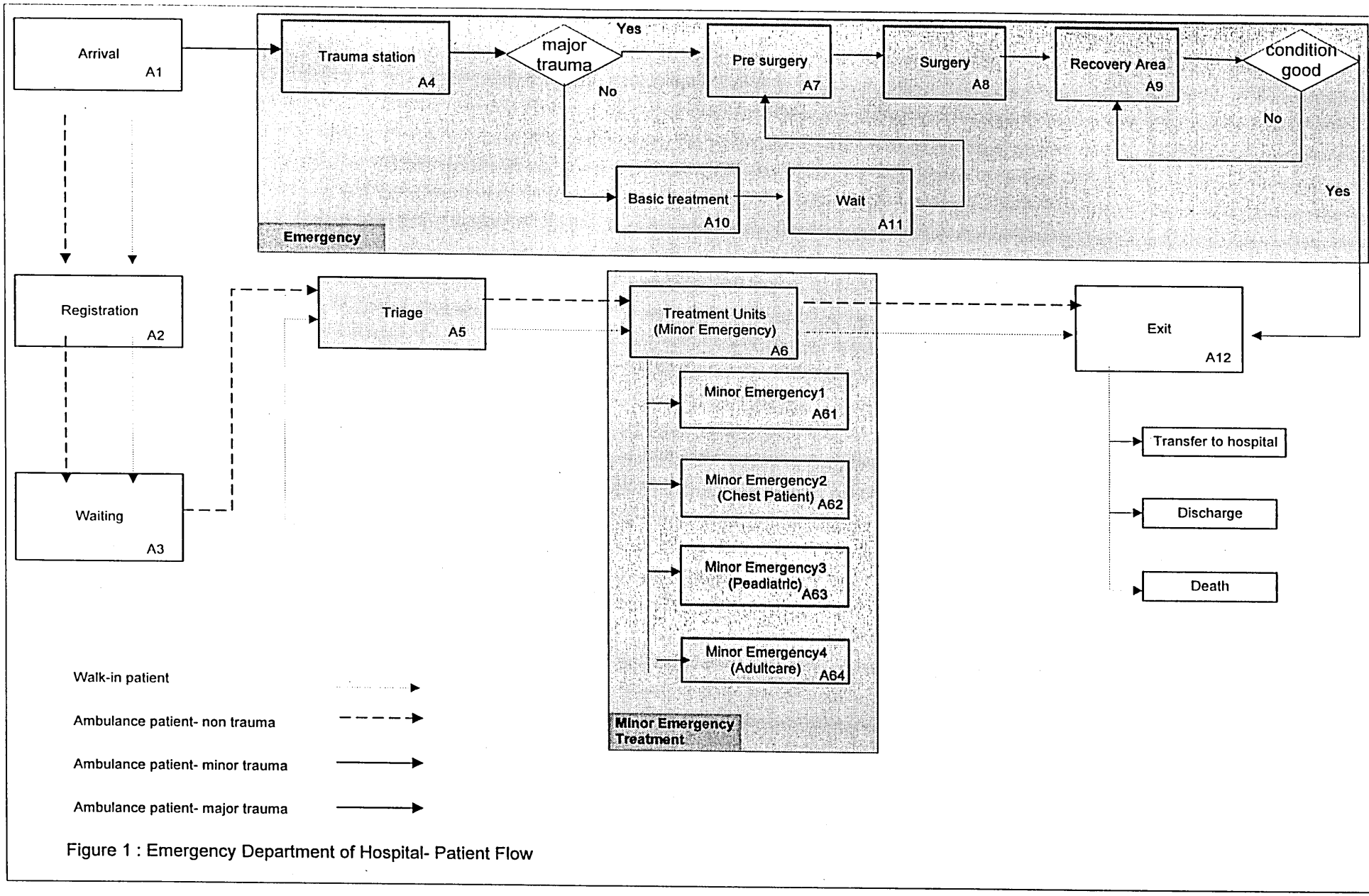


Figure 1 : Emergency Department of Hospital- Patient Flow

1.5 The Simulation Model :

This model was rebuild using the ARENA 3.5 simulation language and a few of the most significant assumptions used in constructing the model were :

- All patients remain at the same acuity level throughout their stay in the ED. The acuity level is assigned during Triage or immediately after entering the ED.
- All trauma patients (minor and major) are equivalent to high acuity level adult wing or CPC patients and do not require separate modelling constructs.

1.6 Model inputs (data) :

Following table present the input data requirement for the simulation model according to patient type and process involved.

Jobs(patient type)	Process	Input data (distribution/probability/time)
Walk-in patient	Arrival	Exp(20).
	Registration	Registration time
	Triage process	Uniform (0.34, 0.21)
	Assign patient acute level & treatment unit Treating at adult care wing Treating at chest pain centre Treating at paediatric care wing Treating at minor emergency section	 Uniform(0.25, 0.45) Uniform(0.30, 0.35) Uniform(0.15, 0.25) Uniform(0.26, 0.35)
Ambulance - non trauma patient	Arrival	Exp(15)
	Registration	Same as above
	Triage process	Same as above
	Assign patient acute level & treatment unit	
Ambulance - Minor Trauma patient	Arrival	Exp(15)
	Sent to trauma station	
	Treating at trauma station - ED doctors, nurses - Special trauma team	 5 minutes Uniform(0.05,0.20)

Jobs(patient type)	Process	Input data (distribution/probability/time)
Ambulance major trauma	Arrival	Exp(12)
	Sent to trauma station	
	Immediate basic treatment	5 minutes
	Transport to operating room	
	Treatment at operating room	Uniform(2,5)
	Monitor the condition	30 minutes

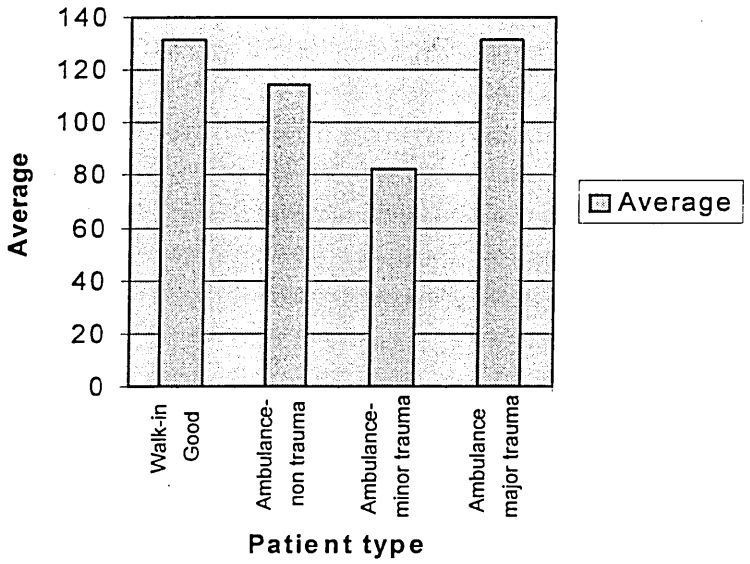
Table 2 : Model Inputs

1.7 Experiment with the model (output) :

Following tables and graphs present the sample out put results generated using the above models. These results not based on real data and it is presented here for demonstration purpose only.

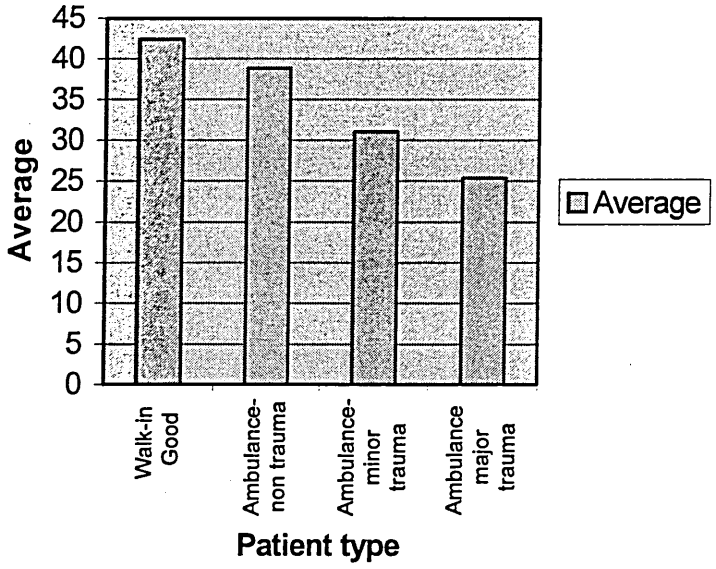
- **Total Time in System by patient type(Time Units : Minutes) :**

Patient type	Average
Walk-in Good	131.34
Ambulance-non trauma	114.52
Ambulance-minor trauma	82.69
Ambulance major trauma	131.50



Graph A : Time in System by patient type

- **Total waiting time by patient type**



Graph B : Total waiting time by patient type

- **Resource Utilisation**

Resource Type	Average (%)
Reg-clerks	32.66
Triage-Nurses	31.26
CPC-Nurses	30.15
CPC-Physicians	32.56
PED-Nurses	28.14
PED-Physicians	29.42
ME-Nurses	31.98
ADCW-Nurse	33.34
ADCW- Physicians	30.88
ED-Nurses	35.23
ED- Physicians	34.21
Trauma-Team	29.30

Table 3 : Resource Utilisation

Sensitivity analysis (what-if) :

Strategy	Criteria
1	Use, two physician for each section for each shift
2	Use, two physician for each section for shift 1
3	Use, one physician for each section for shift 3

Total time in (Average) (Time units : Minutes)	**Strategy 1**	**Strategy 2**	**Strategy 3**
Walk-in Good	133.72	134.60	134.75
Ambulance-non trauma	115.45	116.23	115.86
Ambulance-minor trauma	84.34	86.21	83.32
Ambulance major trauma	131.63	132.75	130.64
Resource Utilisation (%)			
Reg-clerks	48.99	35.93	40.83
Triage-Nurses	46.89	34.39	39.08
CPC-Nurses	45.23	33.17	37.69
CPC-Physicians	48.84	35.82	40.70
PED-Nurses	42.21	30.95	35.18
PED-Physicians	44.13	32.36	36.78
ME-Nurses	47.97	35.18	39.98
ADCW-Nurse	50.01	36.67	41.68
ADCW- Physicians	46.32	33.97	38.60
ED-Nurses	52.85	38.75	44.04
ED- Physicians	51.32	37.63	42.76
Trauma-Team	43.95	32.23	36.63

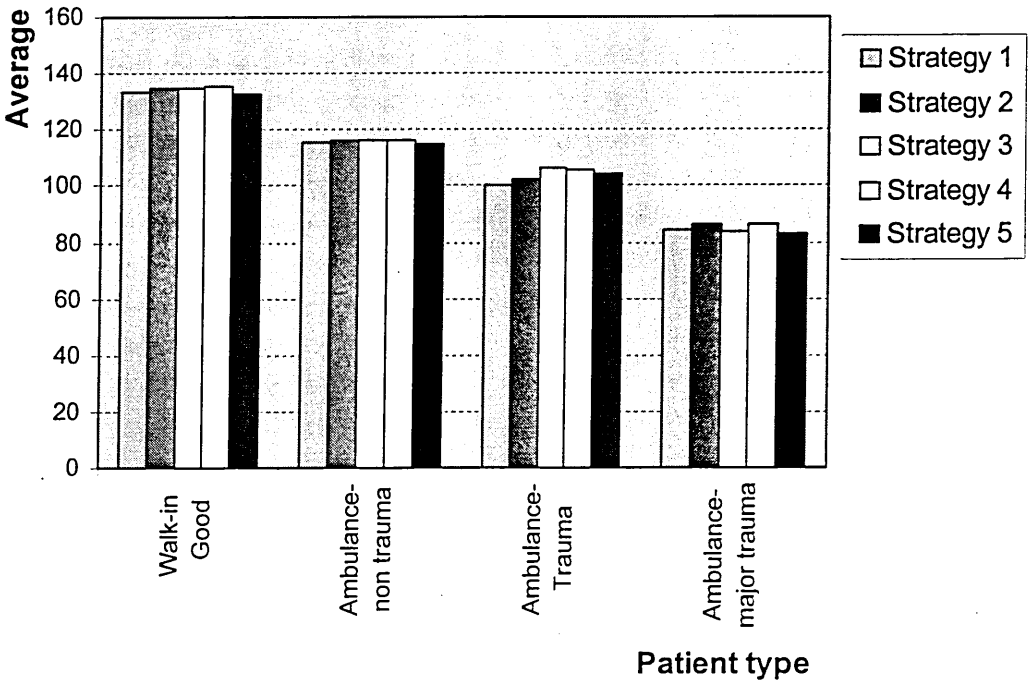
Strategy	Criteria
4	Use, three nurses for each section for shift1.
5	Use, four nurses for shif1 and two nurse shift 2 and 3

Total time in (Average)	**Strategy 4**	**Strategy 5**
Walk-in Good	135.72	132.45
Ambulance-non trauma	116.45	114.78
Ambulance-Trauma	105.56	104.21
Ambulance-minor trauma	86.34	83.25

Table 4 : Sensitivity analysis results

Resource Utilisation (%)	Strategy 4	Strategy 5
Reg-clerks	32.66	39.19
Triage-Nurses	31.26	37.51
CPC-Nurses	30.15	36.18
CPC-Physicians	32.56	39.07
PED-Nurses	28.14	33.77
PED-Physicians	29.42	35.30
ME-Nurses	31.98	38.38
ADCW-Nurse	33.34	40.01
ADCW- Physicians	30.88	37.06
ED-Nurses	35.23	42.28
ED- Physicians	34.21	41.05
Trauma-Team	29.3	35.16

Table 5 : Results of the sensitivity analysis.



Graph C : Total Time (minutes) in System by patient type for different strategies

2. Model 2 : Management of Operations in the Pharmacy of a Hospital

This demonstration simulation model is based on the management of operation in the pharmacy of Tennessee University hospital at Knoxville.

2.1 Problem :

Pharmacies of a hospital play a vital role in hospital environment providing drugs for in-patient, out patient, emergency department, etc. Most of the time it has to deliver the drug orders with least possible delay and zero errors. In order to achieve the above goals, it has to be evaluating the effects of changes in policies and strategies on the performance of a pharmacy.

2.2 Model objective :

To provide hospital management with a versatile laboratory tool that will enable them to evaluate the effects of changes in policies and strategies on the performance of a pharmacy.

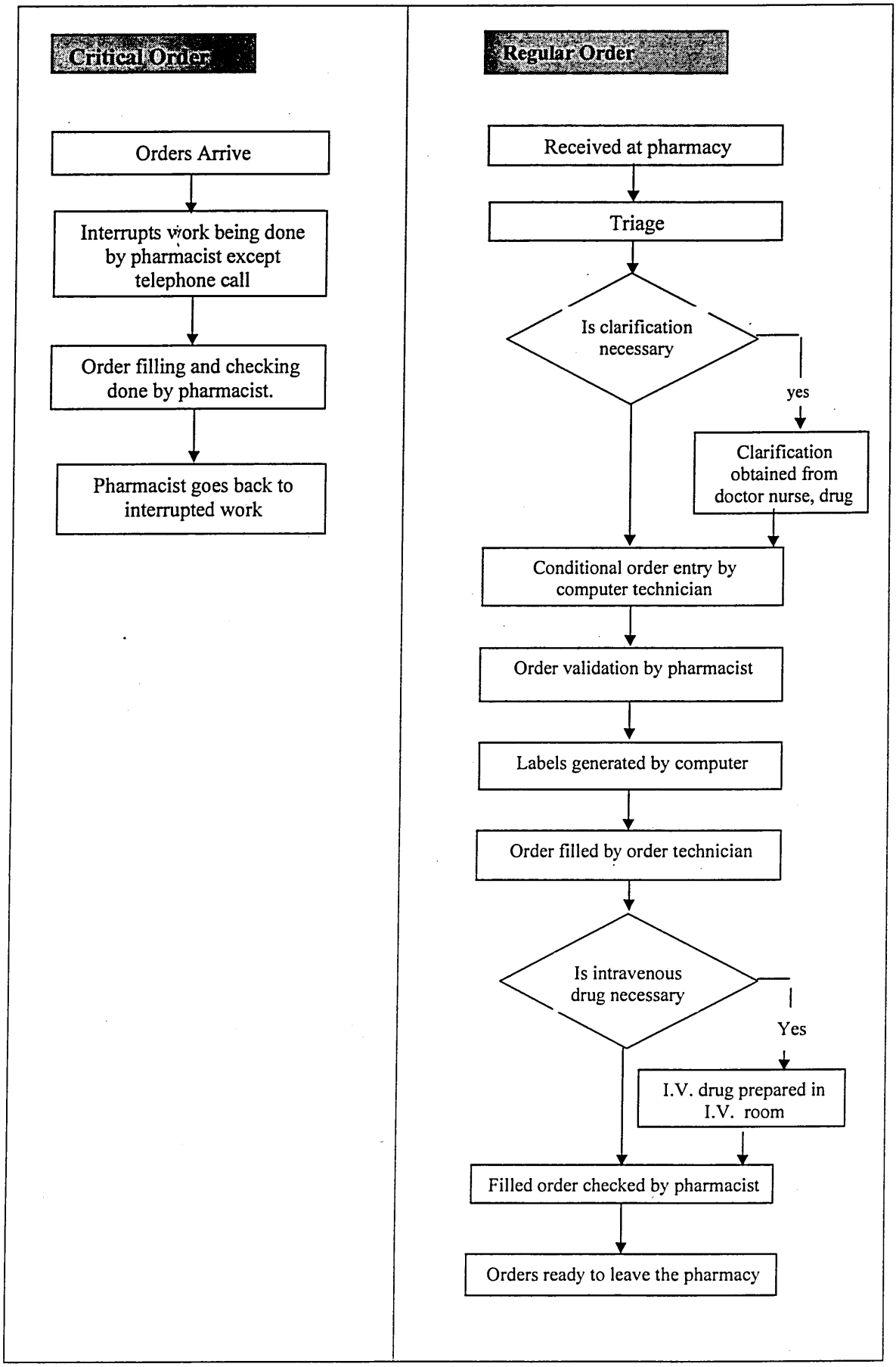
2.3 Background:

This demonstration simulation model is based on the management of operation in the pharmacy of Tennessee University hospital at Knoxville. This model was rebuild-using ARENA 3.5 for demonstration purpose.

- **There are four types of orders / jobs processing in this pharmacy**

1. Critical Orders
2. Regular orders
3. Out door orders
4. Telephone call

2.4 The following diagrams present the flow of each type of orders :


Critical Order
Orders Arrive
Interrupts work being done by pharmacist except telephone call
Order filling and checking done by pharmacist.
Pharmacist goes back to interrupted work
Regular Order
Received at pharmacy
Triage
Is clarification necessary
yes
Clarification obtained from doctor nurse, drug
Conditional order entry by computer technician
Order validation by pharmacist
Labels generated by computer
Order filled by order technician
Is intravenous drug necessary
Yes
I.V. drug prepared in I.V. room
Filled order checked by pharmacist
Orders ready to leave the pharmacy

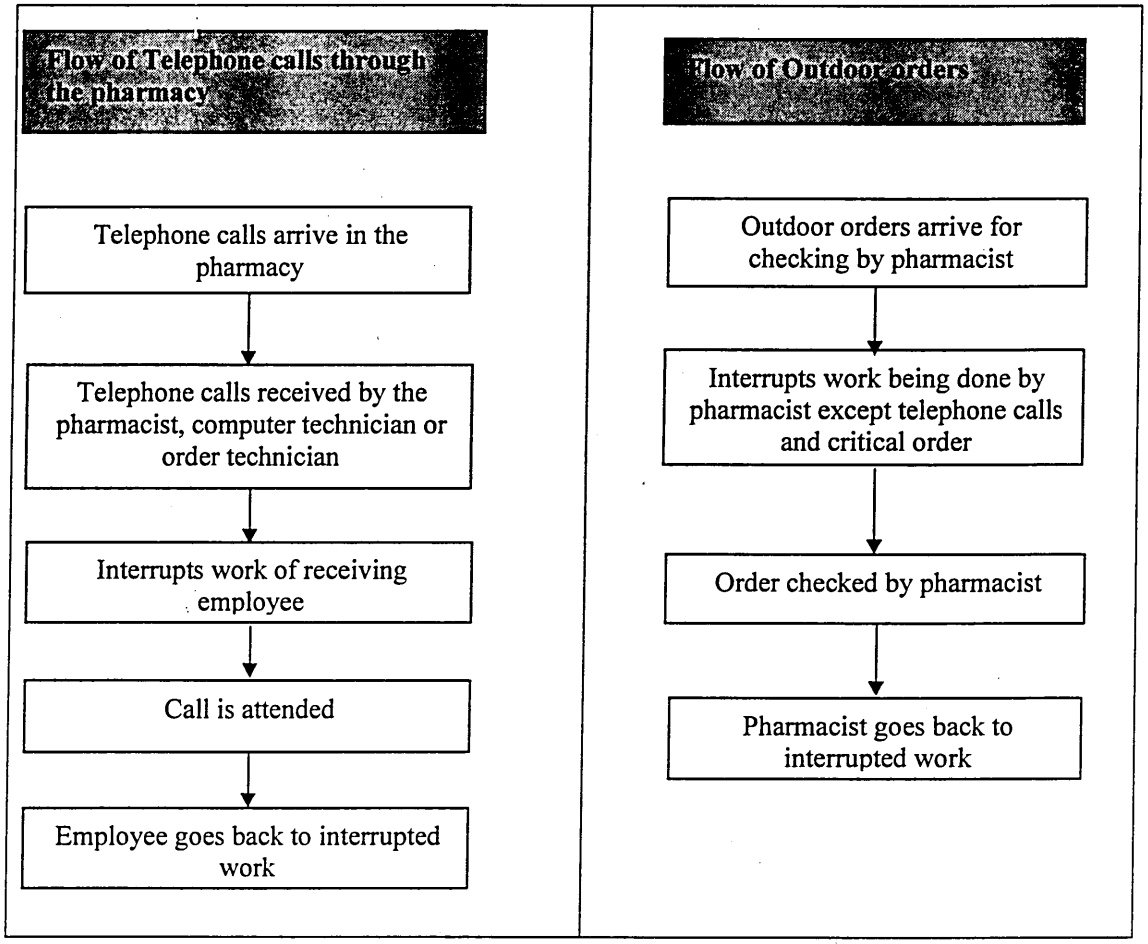


Figure 3 : Order flow through the Pharmacy

2.5 The Simulation Model :

SIMAN, a discrete-event simulation software was used to rebuild this demonstration model of the pharmacy and the important assumptions are noted below:

1. An entity is created to keep track of the start of a new day that is, expiration of 1440 minutes.
2. At the end of every 60 minutes, arrival of regular orders are created, the number arriving varies according to the hours of day
3. Regular orders are delayed if clarification is necessary,
4. Critical orders are created and sent to pharmacy for immediate processing,
5. Outdoor orders are created only between 6am and 6pm , there sent to pharmacy for checking;
6. Telephone calls are created ; 40% are attended by pharmacist, 30% each is attended by computer technician and order technician;
7. Since the number of employees in the pharmacy changes from shift to shift, the model alter the resource levels at 7am, 3pm and 11pm;
8. 20% of regular order are assumed to need an I.V. drug clarification

2.6 Model inputs (data) :

The following tables show the input data need to run this demonstration simulation model. These sample data collected based on the pharmacy of the University of Tennessee.

Description of activity	Distribution	Parameters
Pharmacist triage time	Uniform	0.14, 0.54
Pharmacist order validation time	Empirical	
Pharmacist time checking filled orders	Uniform	0.05, 0.20
Technician time for order entry in computer	Empirical	
Inter-arrival time of critical order	Exponential	30
Delay times of orders needing doctors clarification	Uniform	3, 7
Delay time of orders that need literature survey for clarification	Uniform	2,5
Processing time of critical orders	Uniform	7, 14
Inter-arrival time of outdoor orders	Exponential	15
Pharmacist time for checking outdoor orders	Uniform	1, 2
Time to attend to telephone calls	Uniform	0.1, 0.3
Technician time to fill regular order	Uniform	3, 4

Table 06 : Input Probability Distribution

Shift	Time	Number of		
		Pharmacist	Computer Technician	Order Technician
1	7am - 3pm	5	2	4
2	3pm - 11pm	3	1	2
3	11pm- 7pm	1	1	2

Table 07: Employee combination of different time

2.6 Experiment with model:

Under the model experiment, it have been investigated total time in system of processing orders; utilisation of pharmacist, order technician and computer technician using different criteria.

Total Time in system by order type(All time in Minutes)

Order type	Average
Regular order	34.25
Critical order	7.27
Outdoor order	12.5
Telephone call	0.70

Table 08: Summary statistics of turn around time

Utilisation of resources

Resource	Average (%)
Pharmacists	52
Computer Technicians	91
Order Technicians	77

Table 09: Utilisation of resource

Number of telephone calls waiting for different employee category

Employee	Average	Standard deviation	Minimum Value	Maximum Value
Pharmacist	0.20	0.94	0	12
Computer Technician	0.005	0.02	0	1
Order Technician	0.005	0.02	0	1

Table 10: Number of telephone calls waiting for different employee category

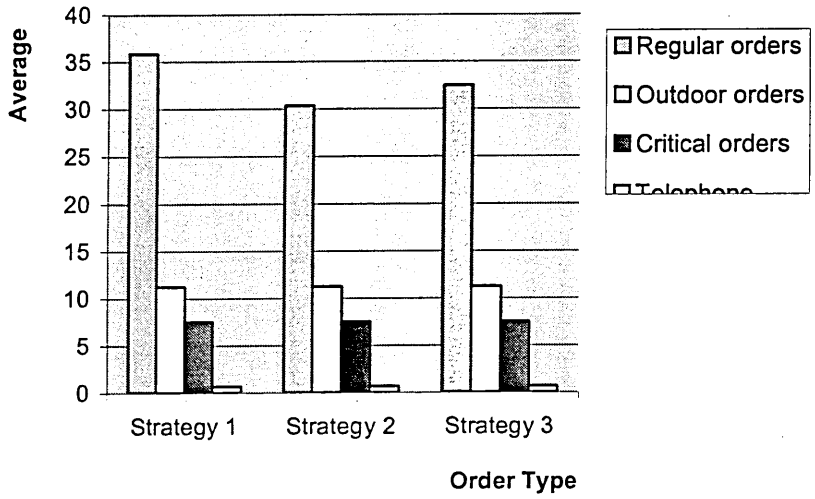
2.7 Sensitivity analysis (What if analysis) :

Total time in system of orders under the different priority strategies

	Strategy 1	Strategy 1	Strategy 1
1st priority	telephone	Critical order	Telephone & critical order
2nd priority	Critical order	Telephone	
3rd priority	Outdoor order	Outdoor order	Outdoor order
4th priority	Regular order	Regular order	Regular order

Total time in system (Average)	Strategy 1	Strategy 2	Strategy 3
Regular orders	35.85	30.33	32.45
Critical orders	7.53	7.53	7.53
Outdoor orders	11.25	11.25	11.25
Telephone calls	0.7	0.7	0.7
Employees utilisation (Average)			
Pharmacists	0.55	0.55	0.55
Computer technician	0.92	0.92	0.92
Order technician	0.78	0.78	0.78

Table 11: Summary statistics of sensitivity analysis



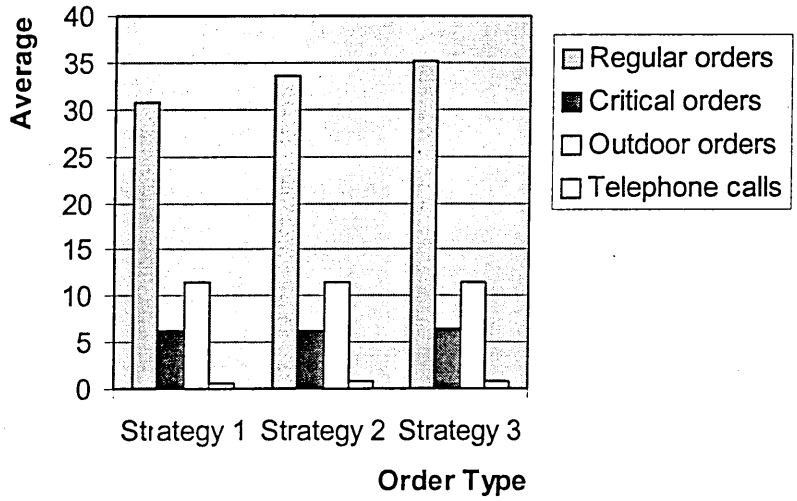
Graph D : Total Time in System by different strategy

Total time in system of orders under the different strategies for use of pharmacists

Strategy	Criteria
1	Use 5,3 and 1 pharmacists in shift 1,2 and 3
2	Use 4,4 and 1 pharmacists in shift 1,2 and 3
3	Use 4,3 and 1 pharmacists in shift 1,2 and 3

Total time in system (Average)	**Strategy 1**	**Strategy 2**	**Strategy 3**
Regular orders	30.72	33.60	35.15
Critical orders	6.27	6.26	6.41
Outdoor orders	11.53	11.49	11.49
Telephone calls	0.70	0.72	0.80
Employees utilisation (Average)			
Pharmacists	0.55	0.55	0.55
Computer technician	0.92	0.92	0.93
Order technician	0.78	0.78	0.76

Table 12: Total time in system by different strategies for use of pharmacists



Graph E : Total Time in System by different strategy

3.2 Limitation of the model

This model has been developed based on what the modeller observed in the pharmacy of the University of Tennessee hospital. While the model is general enough to represent scenarios in 24 hours hospital pharmacies, no claim is made about being adaptable to specific setting in its existing form. This model is only an approximation of the real system. When it considers the utilisation of employees, This model takes into account only those activities that related to processing of orders. In other words there are many activities of pharmacists, computer technicians and order technicians that have not been modelled

3. Model 3 : Management of operation at outpatient clinic

This demonstration model is based on the outpatient clinic in St. John hospital in Detroit, Michigan.

3.1 Model Objective :

Key objectives were to determine the capability to expand, and change the clinic's process to better provide customer service.

3.2 Background :

This simulation model demonstrate the business process reengineering of an outpatient clinic in St. John hospital in Detroit, Michigan. The clinic is host to four clinical specialities : Obstetrics, Gynaecology, Paediatrics and surgery. Each speciality provides different type of patient care.

A patient enter to the outpatient clinic classified as follows:

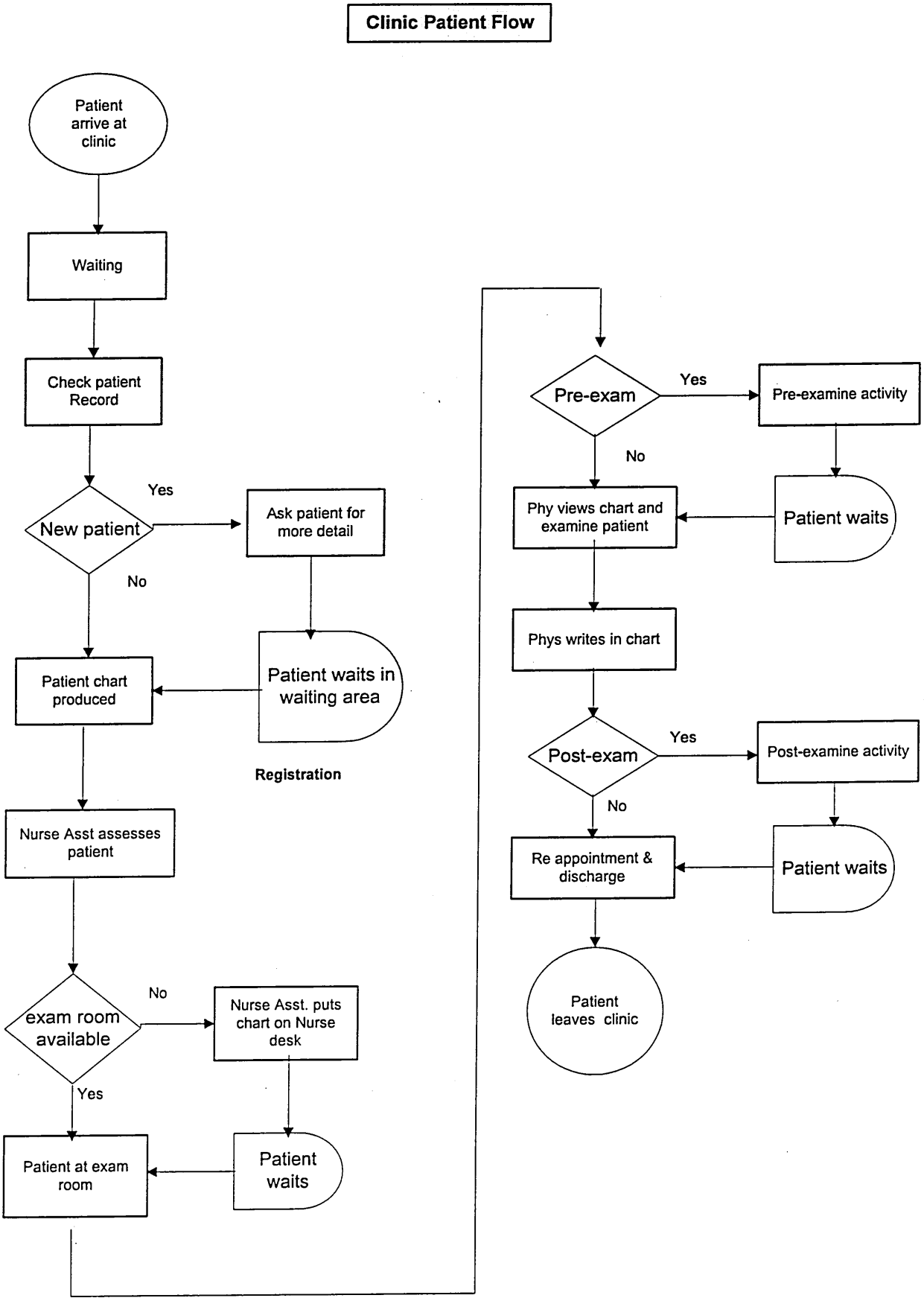
- Obstetrics (OB)
- Gynaecology
- Surgical
- Paediatric

Staff allocation and shift pattern at the initial stage

Resource Type	Capacity	
	Shift 1(7am-2pm)	Shift 2 (2pm-7pm)
Reg. Clerks	3	3
Nurse Assistant s	3	3
OB Nurses	4	3
OB doctors	3	2
Gynaecology nurse/midwife	5	4
Gynaecologists	3	2
Paediatric nurses	5	4
Paediatricians	3	2
Surgical clinic-rooms	3	2
Surgical doctors	2	2
OB exam rooms	3	2
Paediatric exam rooms	3	2
Gynaecology exam rooms	3	2

Table 13 : Staff Allocation

Figure 4: Patient flow through the Clinic



3.4 The simulation model :

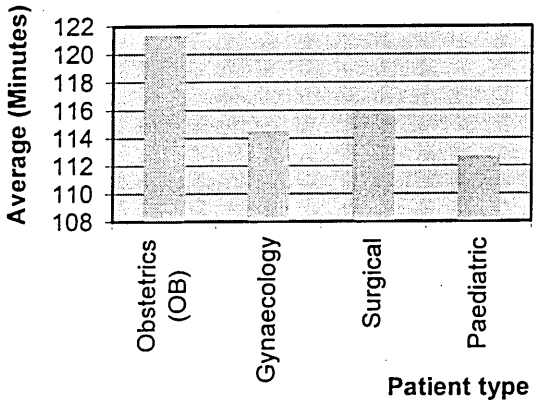
- **Model Inputs (data)**

The following tables show the input data requirements for use to run this demonstration simulation model.

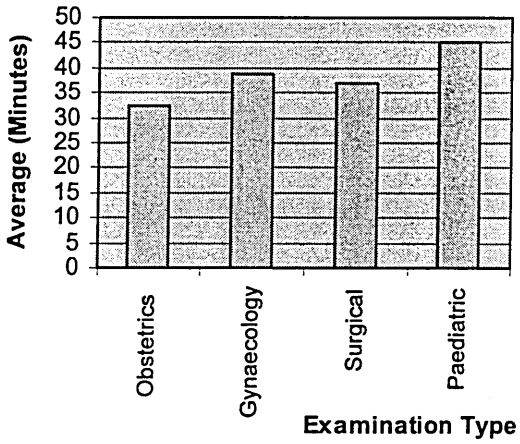
Description of activity	Data type (example)
Patient arrival rate	Normal (.5, .25)
Chance to enter patient for OB examination	With 0.3(probability)
Chance to enter patient for Gynaecology examination	With 0.2 (probability)
Chance to enter patient for Surgical examination	With 0.3 (probability)
Chance to enter patient for Paediatric examination	With 0.2 (probability)
Registration time for patient (new)	Uniform (0.14, 0.54)
Registration delay time for new patient	20 mini.
Registration time for patient(regular)	Uniform (0.13, 0.45)
Nurse asst. time	Uniform (0.05, 0.02)
Pre-examination time for OB treatment	10 min.
Examination time for OB treatment	Uniform (0.06, 0.03)
Post examination time OB treatment	5min.
Pre-examination time for Gynaecology treatment	10min.
Examination time for Gynaecology treatment	Uniform (0.07, 0.04)
Post examination time Gynaecology treatment	5min.
Pre-examination time for surgical treatment	10min.
Examination time for surgical treatment	Uniform (0.04, 0.02)
Post examination time surgical treatment	5min.
Time for reappointment and discharge	10 mini.

Table 14 : Model Inputs

- **Experiment with this model :**



Graph F : Total Time in System by patient type :



Graph G : Waiting time by examination type

- **Utilisation of resources:**

Resource Type	Average (%)
Reg. Clerks	44.04
Nurse Assistant s	24.16
OB Nurses	18.13
OB doctors	38.42
Gynaecology nurses/midwifes	20.32
Gynaecologists	31.25
Paediatric nurses	28.13
Paediatricians	21.36
Surgical clinics	24.63
Surgical doctors	26.31
OB exam rooms	30.12
Paediatric exam rooms	32.00
Surgical exam rooms	34.00
Gynaecology exam rooms	33.85

Table 15 : Resource Utilisation

4 Model 4 : A Simulation model for X-ray facility Management

Improving the quality of care by minimising patient waiting time at an X-ray facility is of critical concern to many healthcare administrators. Following simulation model discuss the planning & management of X-ray facilities at a hospital. This model was based on the simulation models developed for X-ray facilities management at Washington Country hospital (Mark A. et al 1993) and the radiology department at Jackson Memorial Hospital (Martha A. Centeno et al, 2000).

4.1 Model Objective :

Main objective of the simulation model was to identify the causes for the waiting time for the x-ray facility and to investigate means of decreasing the patient waiting time.

4.2 Background :

In this X-ray department, there are two types of x-ray procedures were performed, Special Procedure(SP) and Neuro Procedure(NR). Patient flow through the X-ray department depends on the type of procedure.

The types of patients that are served by X-ray facility vary. There are three primary sources for incoming patients:

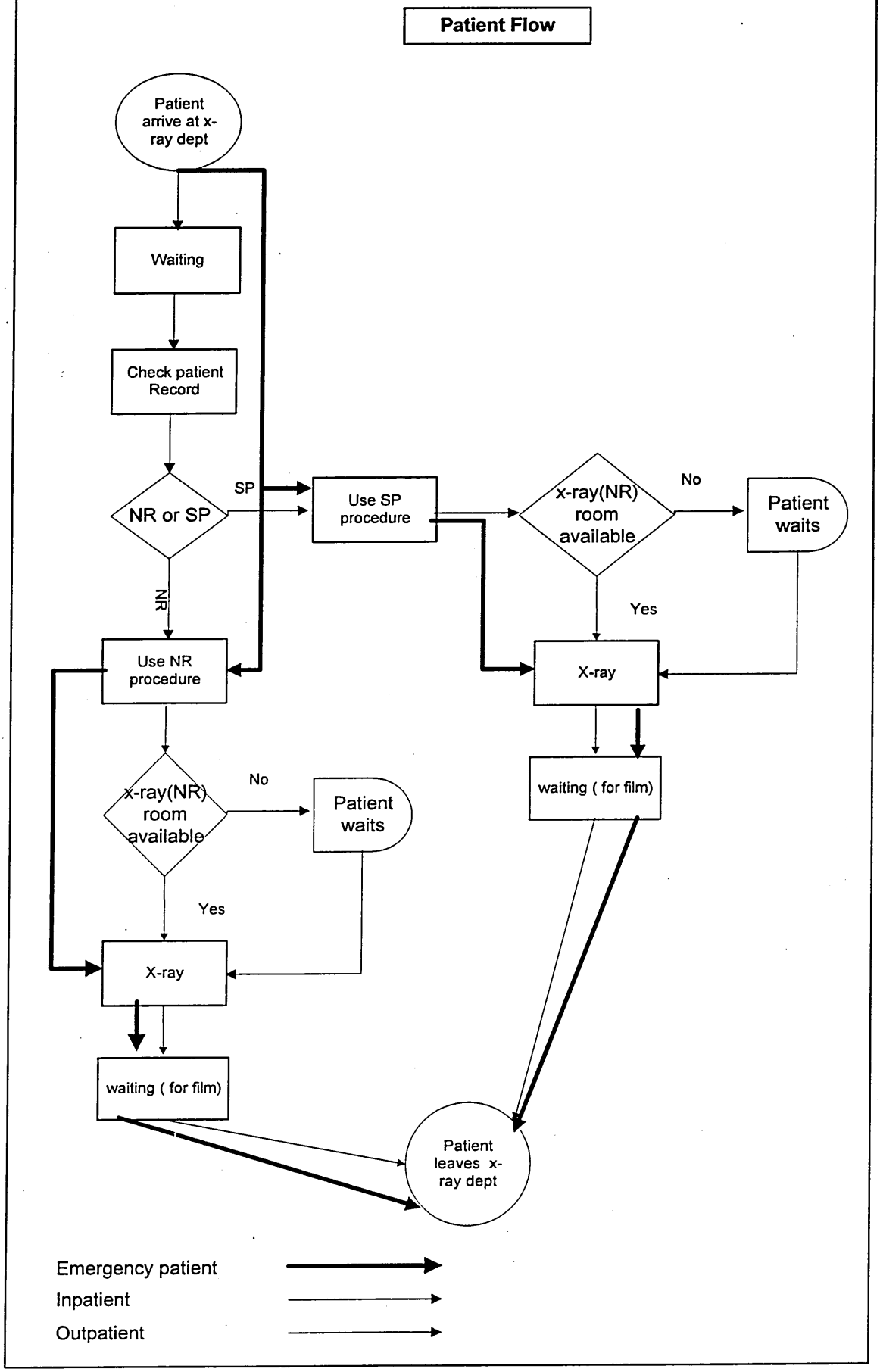
- Emergency Patient
- Indoor patient
- Out door patient

Emergency patient arrivals to the X-ray facility may require additional assistance. In addition, they may have to be served immediately, ahead of other patients waiting in queue.

- **Working hours and staff allocation**

Resource Type	Capacity		
	Shift 1 (7am-2pm)	Shift 2 (2pm-7pm)	Shift 3 (7pm-7am)
Reg. Clerks	2	2	-
Assistants	2	2	1
X-ray technicians	3	2	1
SP X-ray room	3	3	1
NR X-ray room	2	2	1

Table 16 : Staff Allocation



- **Figure 5 : Patient flow through the X-ray department**

4.3 The simulation model :

4.3.1 Model Inputs (data)

The following tables show the input data requirement for used to run this demonstration simulation model.

Description of activity	Data type (example)
Patient arrival rate	Normal (.5, .25)
Chance to enter emergency patient	With 0.3(probability)
Chance to enter outpatient	With 0.2 (probability)
Chance to enter inpatient	With 0.3 (probability)
Registration time for inpatient	Uniform (0.14, 0.54)
Registration time for outpatient	Uniform (0.13, 0.45)
Assistance time for preparation (SP procedure)	Uniform (0.06, 0.02)
Assistance time for preparation (NR procedure)	Uniform (0.05, 0.03)
Technician time for emergency patient (SP procedure)	Uniform (0.04, 0.02)
Technician time for emergency patient (NR procedure)	Uniform (0.05, 0.02)
Technician time for inpatient (SP procedure)	Uniform (0.13, 0.12)
Technician time for inpatient (NR procedure)	Uniform (0.03, 0.02)
Technician time for outpatient (SP procedure)	Uniform (0.04, 0.02)
Technician time for outpatient (NR procedure)	Uniform (0.05, 0.03)
Film processing time (SP procedure)	Uniform (0.06, 0.02)
Film processing time (NR procedure)	Uniform (0.03, 0.02)

Table 17 : Model Inputs

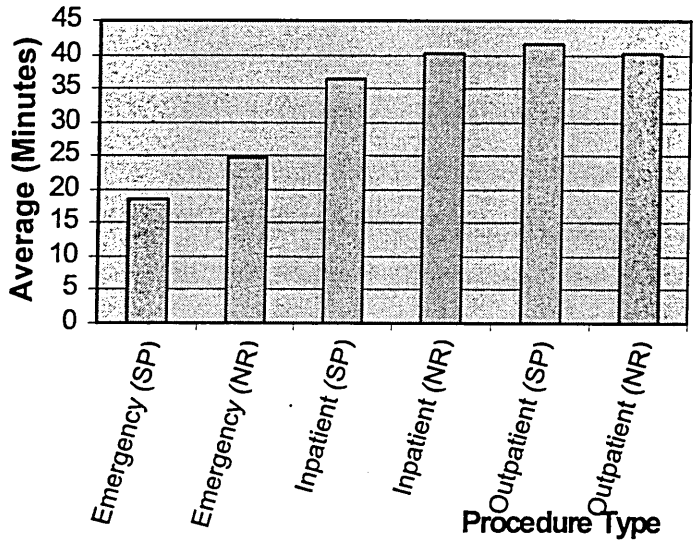
4.3.2 Experiment with this model :

The following tables present the sample results that can be generated using the above simulation model.

- **Total Time in System by patient type :**

Patient type	Average (Minutes)
Emergency (SP procedure)	121.34
Emergency (NR procedure)	124.52
Inpatient (SP procedure)	113.99
Inpatient (NR procedure)	132.69
Outpatient (SP procedure)	131.50
Outpatient (NR procedure)	133.89

Table 18 : Total Time in System



Graph H : Waiting time by patient type

- **Utilisation of resources:**

Resource Type	Average (%)
Reg. Clerks	45
Assistants (SP)	40
Assistants(NR)	49
X-ray technician 1(SP)	51
X-ray technician1(NR)	38
SP X-ray room 1	44
SP X-ray room 2	56
SP X-ray room 3	60
NR X-ray room 1	37
NR X-ray room 2	41

Table 19 : Resource utilisation

- **Sensitivity Analysis (what if)**

Strategy	Criteria
1	Use, 2 technicians (SP), 2technicians (NR) for shift 1 and 2
2	Use, 1technician +2 assistance (SP), 1technician +2 assistance (NR) for shift 1 and 2
3	Use, 2technicians X-ray(SP), technician film devp (SP) 2technicians X-ray(NR), technician film devp (NR) in shift 1 and 2

Total time in system (Average)	**Strategy 1**	**Strategy 2**	**Strategy 3**
Emergency (SP procedure)	11.72	11.60	10.15
Emergency (NR procedure)	11.27	12.26	11.41
Inpatient (SP procedure)	21.53	21.49	21.49
Inpatient (NR procedure)	20.70	20.72	20.80
Outpatient (SP procedure)	22.41	22.53	22.15
Outpatient (NR procedure)	23.15	22.95	22.57
Resource utilisation (Average)			
Reg. Clerk	47.99	33.93	41.83
Assistant1 (SP)	46.89	34.39	39.08
Assistant1(NR)	45.23	33.17	37.69
X-ray technician 1(SP)	48.84	35.82	40.70
X-ray technician1(NR)	42.21	30.95	35.18
SP X-ray room 1	44.13	32.36	36.78
SP X-ray room 2	47.97	35.18	39.98
SP X-ray room 3	50.01	36.67	41.68
NR X-ray room 1	46.32	33.97	38.60
NR X-ray room 2	52.85	38.75	44.04

Strategy	Criteria
4	Add new SP X-ray room and new NR X-ray
5	Add one SP X-ray room and two NR X-ray rooms
6	Add two SP X-ray rooms and one NR X-ray room

Total time in system (Average)	**Strategy 1**	**Strategy 2**	**Strategy 3**
Emergency (SP procedure)	185.72	192.60	202.15
Emergency (NR procedure)	11.27	11.26	11.41
Inpatient (SP procedure)	1.53	1.49	1.49
Inpatient (NR procedure)	0.70	0.72	0.80
Outpatient (SP procedure)			
Outpatient (NR procedure)			

Table 20 : Sensitivity analysis results

5 Model 5 : A simulation model for Maternity Process Management

In this example model, describe the simulation process of a maternity ward activity. A model was based on the simulation model developed by William C. Johnson ,1998 for maternity facilities management at Miami Valley hospital in USA .

5.1 Model Objective :

This simulation model was developed to solve the problems of customer satisfactions, utilisation and patient flow.

5.2 Background :

In this maternity ward, there are four major sections, Antenatal clinic, Normal delivery area, emergency delivery area and postnatal ward. There are three different type of patients enter to this maternity ward. They are :

Clinic patient
Low risk patient
High risk patient

Some of the low risk patients are in false labor and return to home within a few hours. The remainder of patients at low risk complete their labor in individual labor room.
Patients typically deliver in the labor room and later are moved to the postnatal ward. After staying a few days Mom and baby are discharged from the ward.

The following diagram present the flow of each patient type

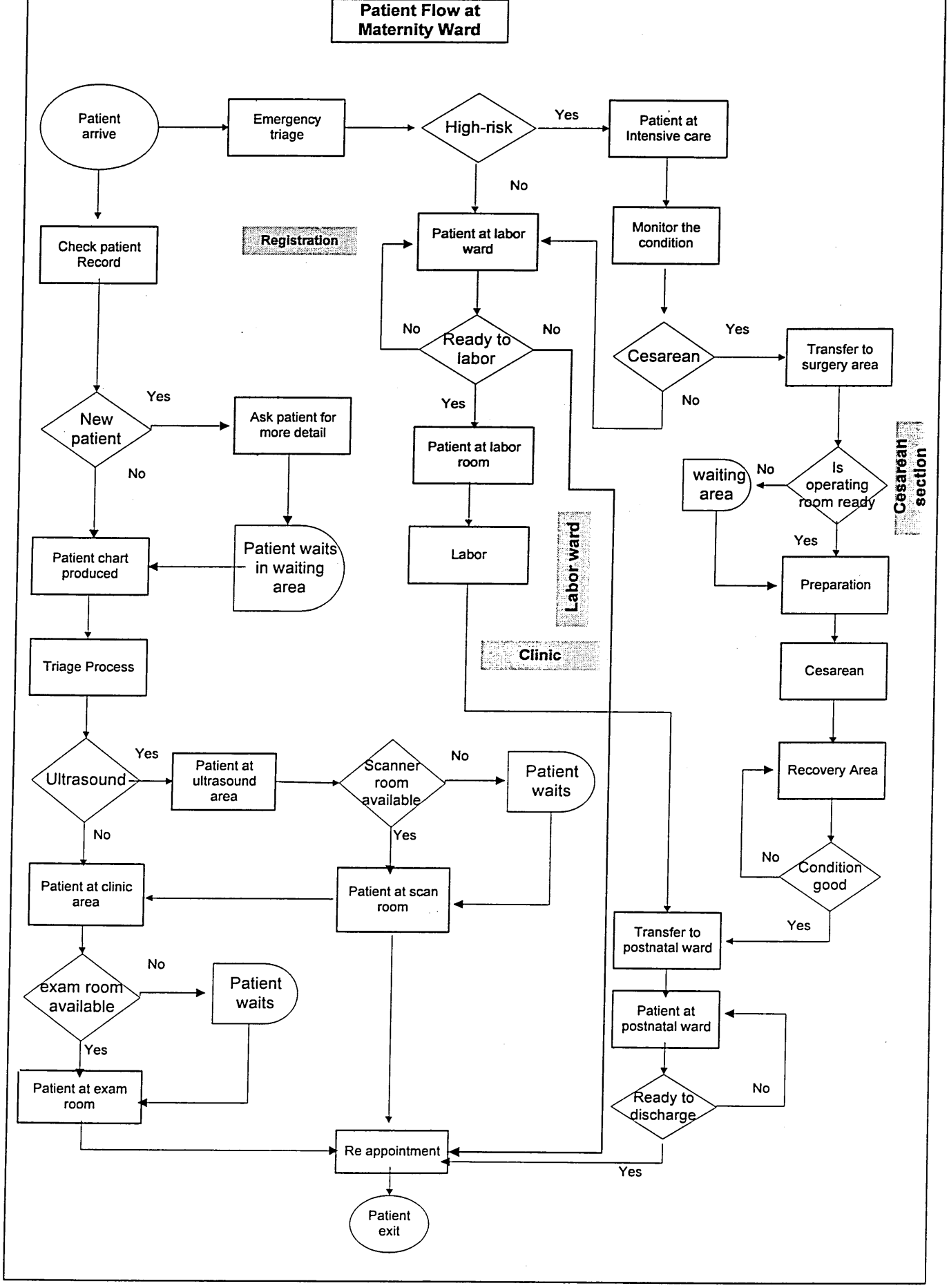


Figure 6 : Patient flow through the Maternity Hospital

5.3 Model Inputs :

Description of activity	Data type (example)
Patient arrival rate	Normal (.5, .25)
Chance to enter patient for Antenatal clinic	With 0.5(probability)
Chance to enter patient for low-risk triage	With 0.3 (probability)
Chance to enter patient for high-risk triage	With 0.2 (probability)
Registration time for clinic patient	Uniform (0.14, 0.54)
Triage time for clinic patient	Uniform (0.13, 0.45)
Examination time for clinic patient	Uniform (0.16, 0.32)
Ultrasound exam time	Uniform (0.15, 0.13)
Patient time at labor ward	Uniform (0.14, 0.02)
Delivery time at labor room	Uniform (0.05, 0.02)
Intensive care time	Uniform (0.13, 0.12)
Pre cesarean time	Uniform (0.03, 0.02)
Cesarean time	Uniform (0.04, 0.02)
Post cesarean time (Recovery area)	Uniform (0.05, 0.03)
Patient time at postnatal ward	Uniform (0.14, 0.12)
Time for reappointment and discharge	Uniform (0.05, 0.03)

Table 21 : Model Input

5.4 Resource allocations at initial stage :

Resource Type	Capacity	
	(6 am-6pm)	(6pm-6am)
Reg. Clerks	2	
Triage Nurses	2	2
Nurse Assistant1 Ultrasound	2	2
Technician ultrasound	2	2
Nurses, clinic	4	3
Physicians, clinic	4	3
Ult-scan room	2	2
Beds at labor ward	30	30
Doctors, labor ward	3	2
Labor rooms	3	3
Nurse Assistants-labor ward	4	4
Nurses labor ward	4	3
Gynaecologists	3	2
Surgeon	2	1
Doctors, surgery	3	2
Nurses, surgery	4	3
Beds, postnatal ward	25	25
Nurse Assistants-postnatal ward	3	3
Nurses , postnatal ward	3	3
Doctors, postnatal ward	3	2

Table 22: Resource Allocation

5.5 Experiment with this model :

The following tables describe the sample output results that can be generated using the above simulation model. The data listed in the following tables are not real simulation model outputs and it used only for demonstration purpose.

- **Total Time in System by patient type :**

Patient type	Average (Minutes)
Clinic patient	135.34
Clinic with ultrasound scanning	175.42
Low-risk patient	435.44
High risk patient	213.26

Table 23 : Total Time in System

- **Waiting time**

Area	Average (Minutes)
Waiting time for clinic patient	45.36
Waiting time ultrasound scanning only	70.25
Waiting time for labor room	125.41
Waiting time for surgery	30.46

Table 24 : Waiting time

Utilisation of resources:

Resource Type	Average (%)
Reg. Clerks	48.50
Triage Nurses	46.89
Nurse Assistant1 Ultrasound	43.23
Technician ultrasound	48.84
Nurses, clinic	42.21
Physicians, clinic	41.13
Ult-scan room	47.97
Beds at labor ward	50.01
Labor rooms	46.32
Nurse Assistants-labor room	48.99
Nurses labor room	46.89
Gynaecologists	45.23
Surgeon	48.84
Doctors, surgery	42.21
Nurses, surgery	43.13

Table 25 : Resource utilisation

5.6 Sensitivity analysis

Strategy	Criteria
1	Use, extra nurse for each shift for each section
2	Use, add two labor rooms for each shift
3	Use, two additional doctors for clinic section

Total time in (Average) (Time units : Minutes)	**Strategy 1**	**Strategy 2**	**Strategy 3**
Clinic patient	133.72	134.60	134.75
Clinic with ultrasound scanning	165.45	166.23	165.86
Low-risk patient	414.34	416.21	413.32
High risk patient	231.63	232.75	230.64
Resource Utilisation (%)			
Reg. Clerks	48.99	35.93	40.83
Triage Nurses	46.89	34.39	39.08
Nurse Assistant1 Ultrasound	45.23	33.17	37.69
Technician ultrasound	48.84	35.82	40.70
Nurses, clinic	42.21	30.95	35.18
Physicians, clinic	44.13	32.36	36.78
Ult-scan room	47.97	35.18	39.98
Beds at labor ward	50.01	36.67	41.68
Labor rooms	46.32	33.97	38.60
Nurse Assistants-labor room	52.85	38.75	44.04
Nurses labor room	51.32	37.63	42.76
Gynaecologists	43.95	32.23	36.63
Surgeon	44.13	32.36	36.78
Doctors, surgery	47.97	35.18	39.98
Nurses, surgery	43.13	31.36	36.78

Table 26 : Sensitivity analysis results

APPENDIX C

Development of Specifications and Prototypes for Healthcare Oriented Simulation Templates

1. Area 2 : Emergency Department of a hospital

Emergency department is one of the busiest places in hospital environment. Efficient allocation and utilisation of scare resources, reducing patient waiting and treating critical patients are few of the challenges facing by emergency department staff in their day to day work.

1.1 Step 1: Analysis of the patient flow through the emergency department

The following flow chart diagram presents the patient flow through the emergency department.

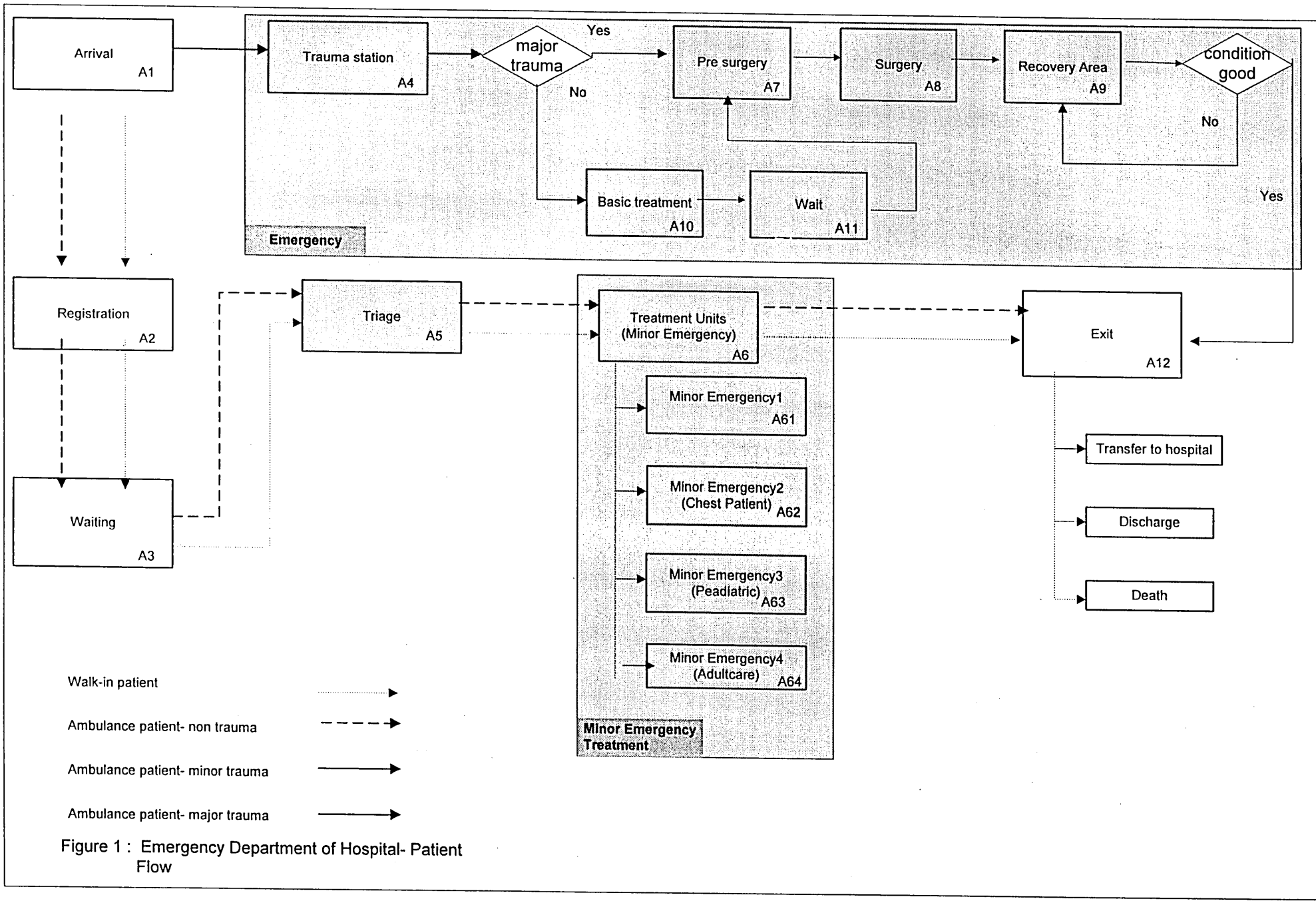


Figure 1 : Emergency Department of Hospital- Patient Flow

- **Detail analysis of the each steps of the above order flow**

Jobs	Process	Resource	Input data (distribution/probability/time)
Walk-in patient	Arrival		
	Registration	Admin staff	
	Waiting		
	Triage process	Triage Nurses/Technician/Ed doctors	
	Treatment process (minor emergency)	Ed doctors/ Assistant / Ed nurses	
	Exit		
Ambulance - non trauma patient	Arrival		
	Registration	Admin staff	
	Waiting		
	Triage process	Triage Nurses/Technician/Ed doctors	
	Treatment process (minor emergency)	Ed doctors/ Assistant / Ed nurses	
	Exit		
Ambulance - Minor Trauma patient	Arrival		
	Sent to trauma station	Nurses / Assistant	
	Basic treatment	Ed doctors / Nurses	
	Pre surgery	Ed doctors / Nurses	
	Surgery	Trauma team	
	Recovery	Ed doctors / Nurses	
	Exit		
Ambulance patient - major trauma	Arrival		
	Sent to trauma station	Nurses / Assistant	
	Pre surgery	Ed doctors / Nurses	
	Surgery	Trauma team	
	Recovery	Ed doctors / Nurses	
	Monitor the condition	Ed doctors / Nurses	
	Exit		

1.2 Step2: Developing Specification and prototype templates for Emergency Department

- **Opportunities for sample templates :**

- Minor Emergency
- Triage process
- Surgery
- Surgeon / consultant

Prototype templates and specifications for the above templates

Following figures will present the prototype template for above places.

Figure 2 : sample template For : Minor Emergency (see page)

Figure 3 : sample template For : Triage process

Figure 4 : sample template For : Surgeon / consultant

Figure 5 : sample template For : Surgery

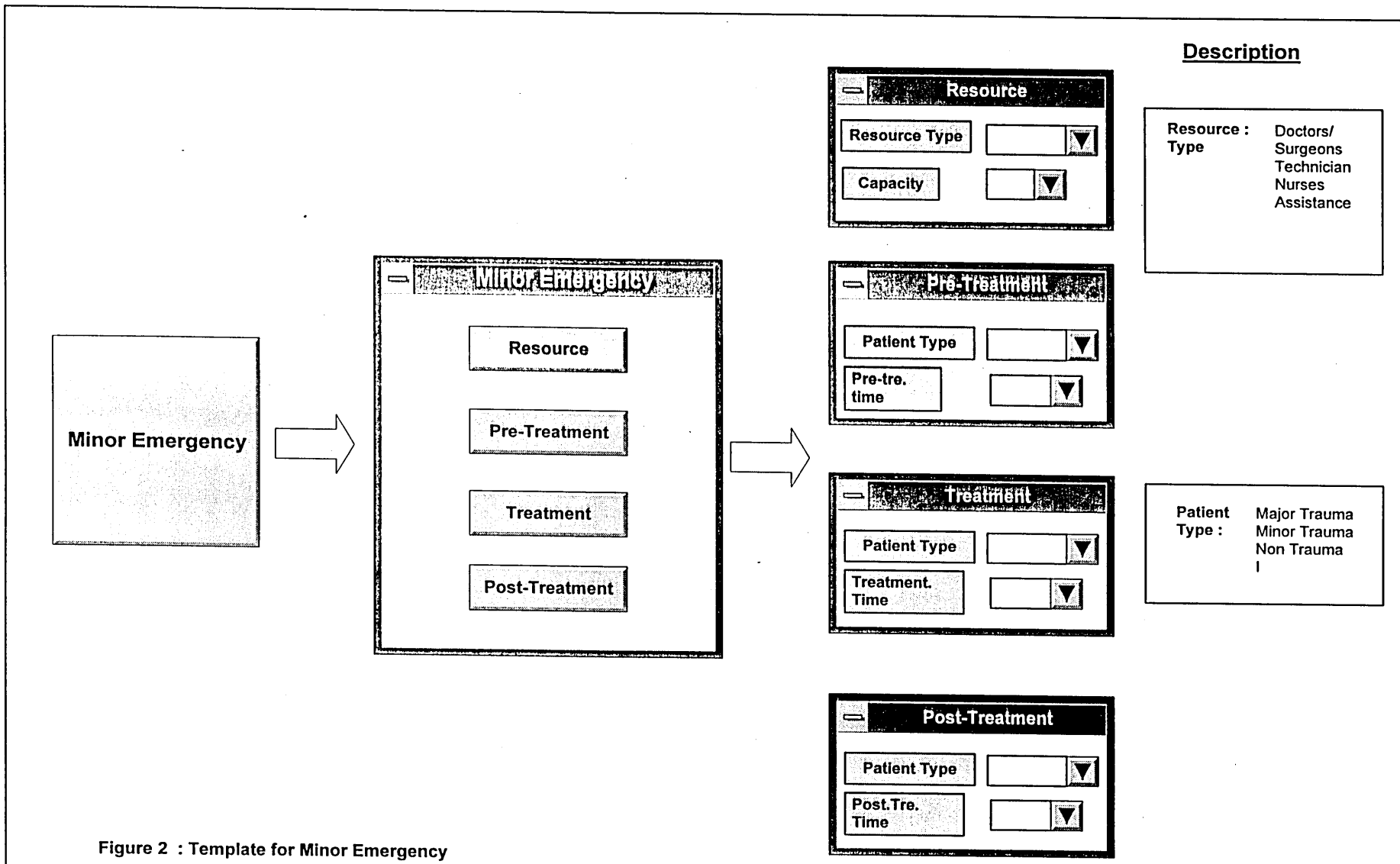


Figure 2 : Template for Minor Emergency

Figure 3 : Emergency Dept :
Template for Triage Process

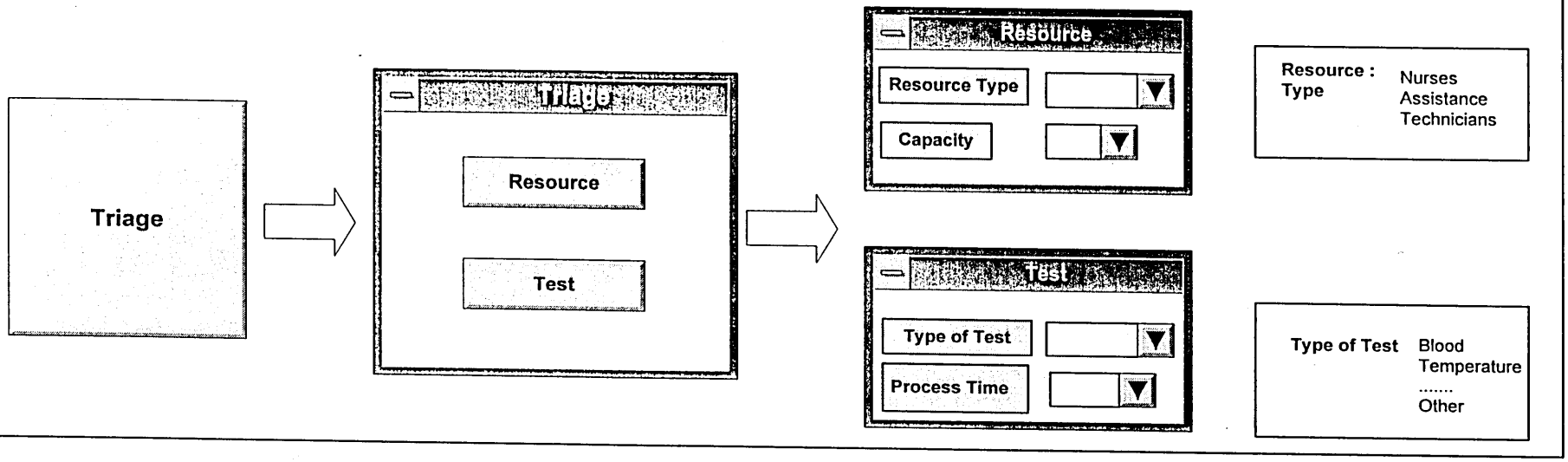
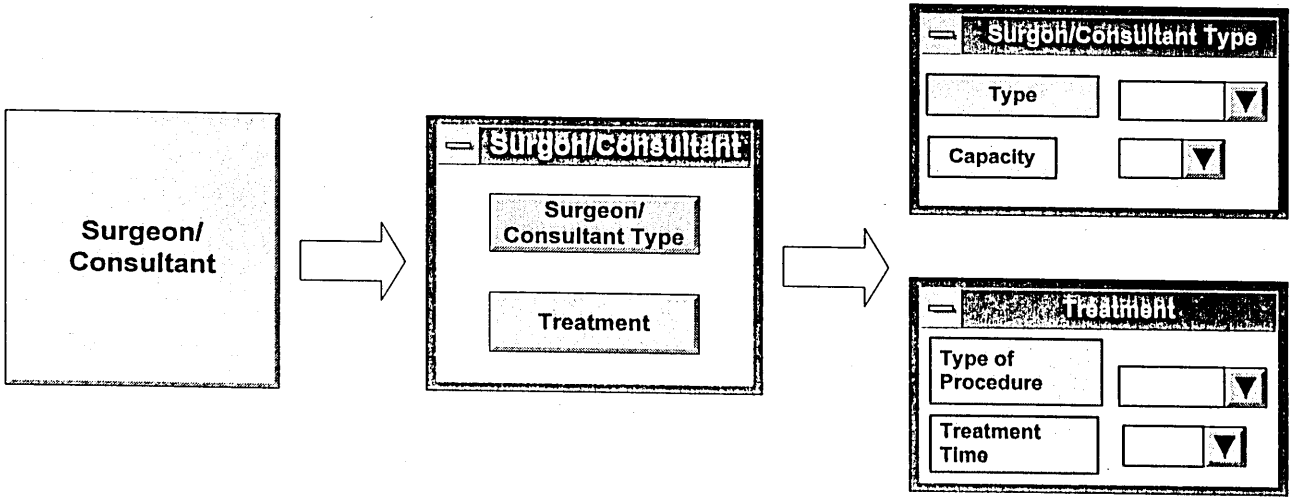


Figure 4 : Emergency Dept : Template for
Surgeon/ consultant



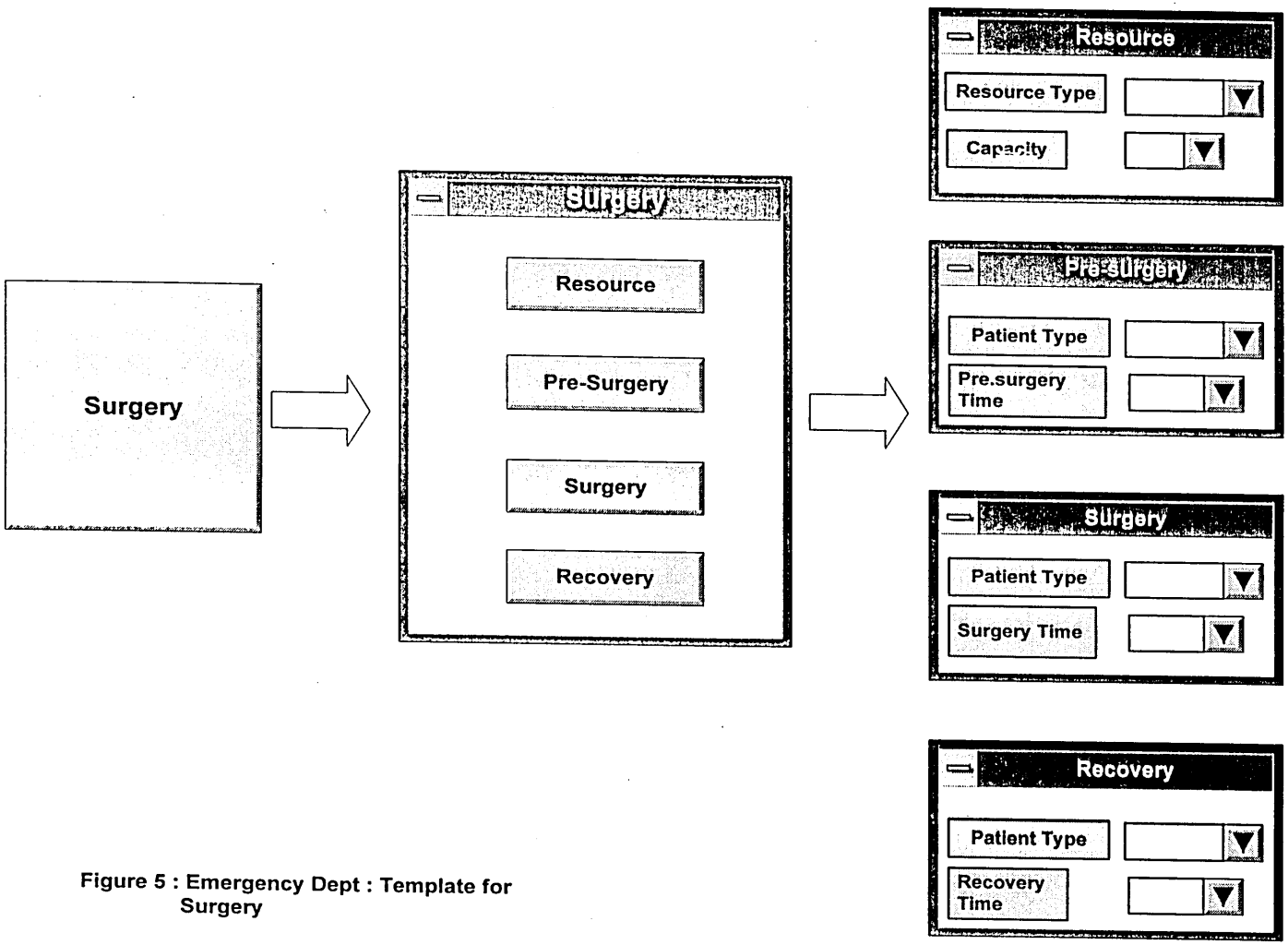


Figure 5 : Emergency Dept : Template for Surgery

2 Area 3 : Outpatient clinic

Outpatient clinic provides different type of healthcare facilities for outpatients in hospital environment. Some of them are OB examinations, Gynaecology speciality, and surgical speciality and paediatric speciality services.

Utilisation of resources, allocation of staff and log waiting time are few of major problems faced by outpatient clinic administrators. Computer simulation technology can be used to review the clinic's facility needs, highlight any bottlenecks and test various alternative processes to improve the above situation.

2.1 Step 1 : Analysis of patient flow through the Outpatient Clinic.

The following diagram presents the patient flow through the outpatient clinic. In this diagram, we consider only four types of healthcare facilities provided by outpatient clinic. These facilities are OB facilities, Surgical treatment facilities, Gynaecology facilities and paediatric treatment facilities.

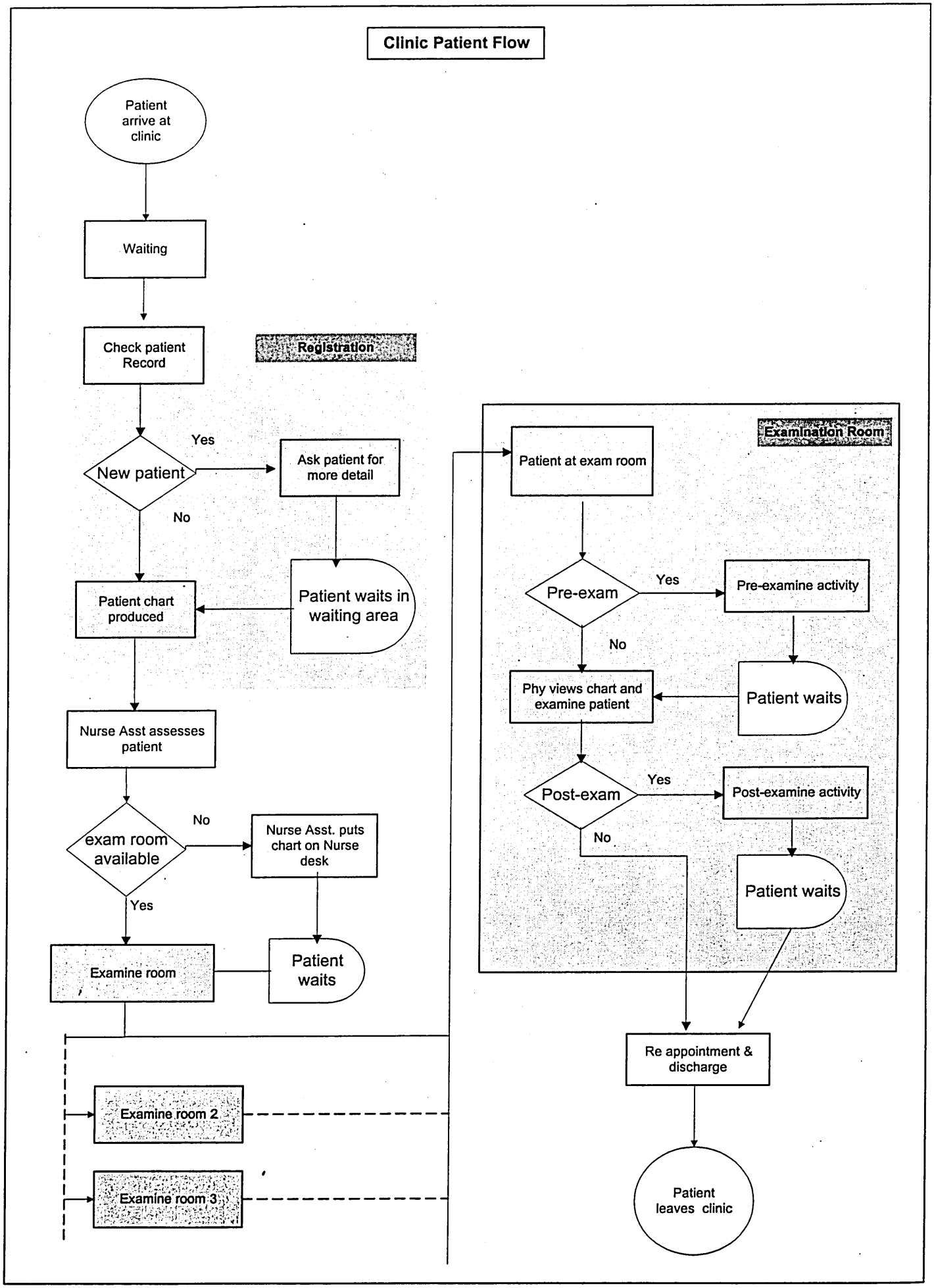


Figure 6 : Patient flow through Outpatient clinic

- **Detail analysis of each steps of the above patient flow.**

Description of activity	Resource involved	Input data (Distr. /probability..)
Patient arrival • to enter patient for OB examination • to enter patient for Gynaecology examination • to enter patient for Surgical examination • to enter patient for Paediatric examination		Arrival Probability
Registration • New patient • Regular patient	Admin staff	Registration time
OB Treatment • Pre-examination for OB treatment • Examination for OB treatment • Post examination for OB treatment	Nurse / Nurse Assi. OB doctors / Nurse Nurse / OB doctors	Pre examination time Examination time Post examination time
Gynaecology Treatment • Pre-examination for Gynaecology treatment • Examination for Gynaecology treatment • Post examination Gynaecology treatment	Nurse / Nurse Assi. Gynaecologist/ Nurse Nurse / Gynaecologist	Pre examination time Examination time Post examination time
Surgical Treatment • Pre-examination for surgical treatment • Examination for surgical treatment • Post examination for surgical treatment	Nurse / Nurse Assi. doctors / Nurse Nurse / doctors	Pre examination time Examination time Post examination time
Paediatrician Facilities • Pre-examination for Paediatrician treatment • Examination for Paediatrician treatment • Post examination for Paediatrician treatment	Nurse / Nurse Assi. doctors / Nurse Nurse / doctors	Pre examination time Examination time Post examination time
Reappointment and discharge		Reappointment time

2.2 Step 2 : Developing Specification and prototype templates for Out patient clinic

- **Identify the possible places for simulation template in each area**

    - Clinic Reception
    - Clinic Examination

- **Prototypes and specifications for above possible templates.**

Following figures present the sample templates for above places.

Figure 7 : sample template For : Clinic Reception (see page)

Figure 8 : sample template For : Clinic Examination (see page)

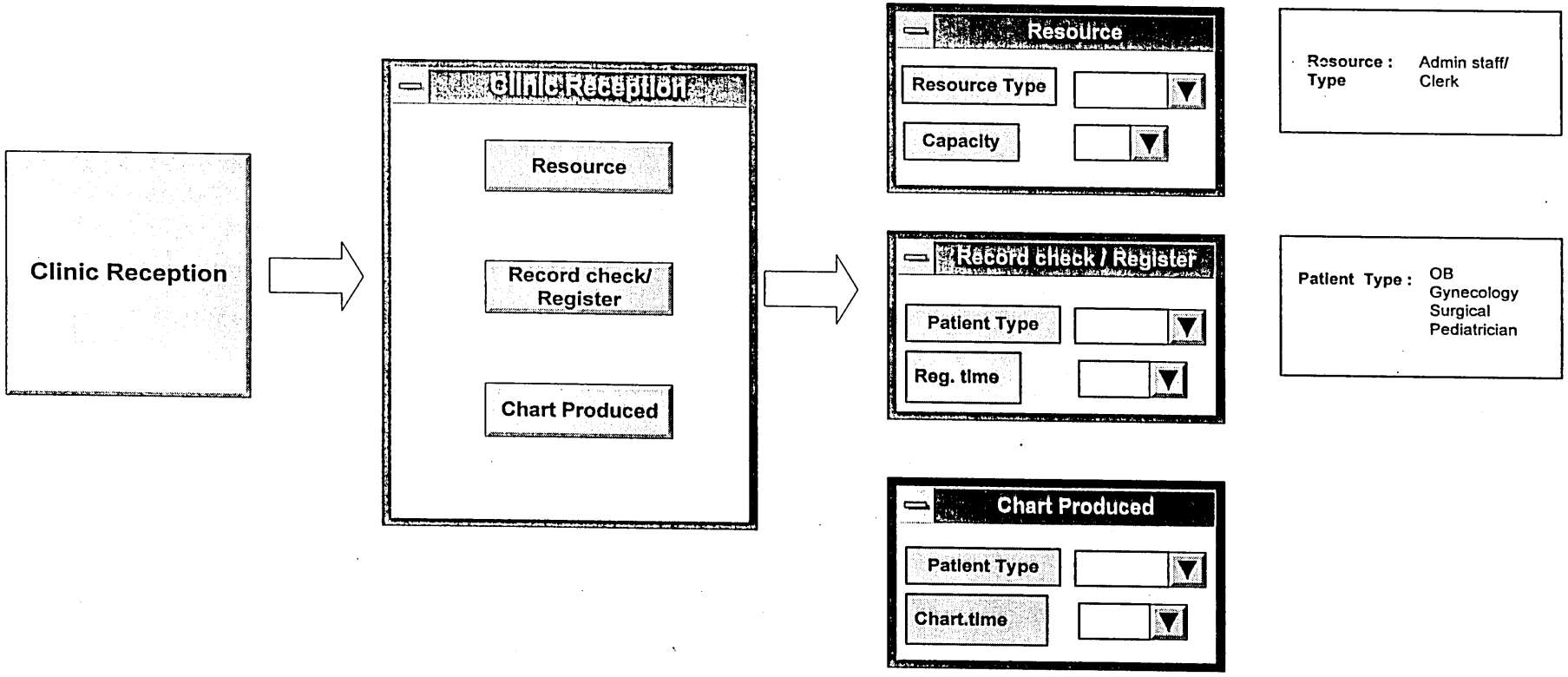
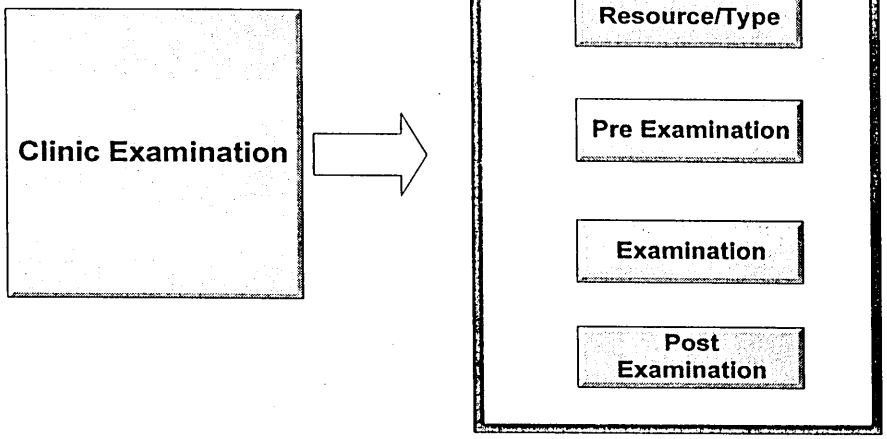
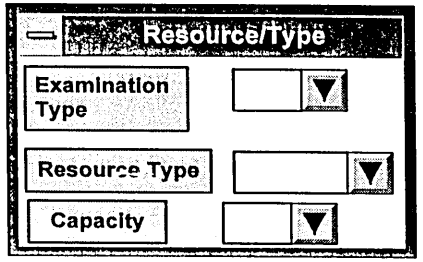
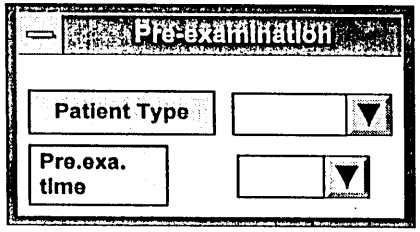
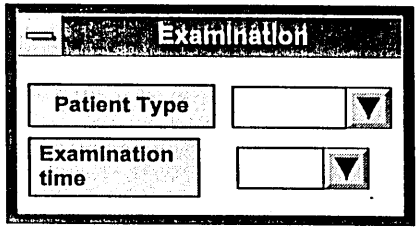


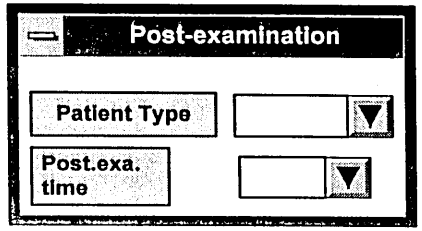
Figure 7 : Outpatient Clinic Template for Clinic Reception











Description

Examination Type :	OB Gynecology Surgical Pediatrician
Resource Type :	OB doctors / Nurses/GYN/ Surgical doctors/ Peadiatrician

Patient Type :	OB Gynecology Surgical Pediatrician

Figure 8 : Outpatient Clinic
Template for Clinic examination

3 Area 4 : X-ray Department

Improving the quality of care by minimising patient waiting time at an X-ray facility is one of critical concern to many healthcare administrators. Most of the time, efficiency of major healthcare facilities is depending on small department like X-ray.
In this area, simulation can be play grater role to improve the system performance by identifying bottlenecks and testing various alternative processes.

3.1 Step 1 : Analysis of patient flow through the Outpatient Clinic.

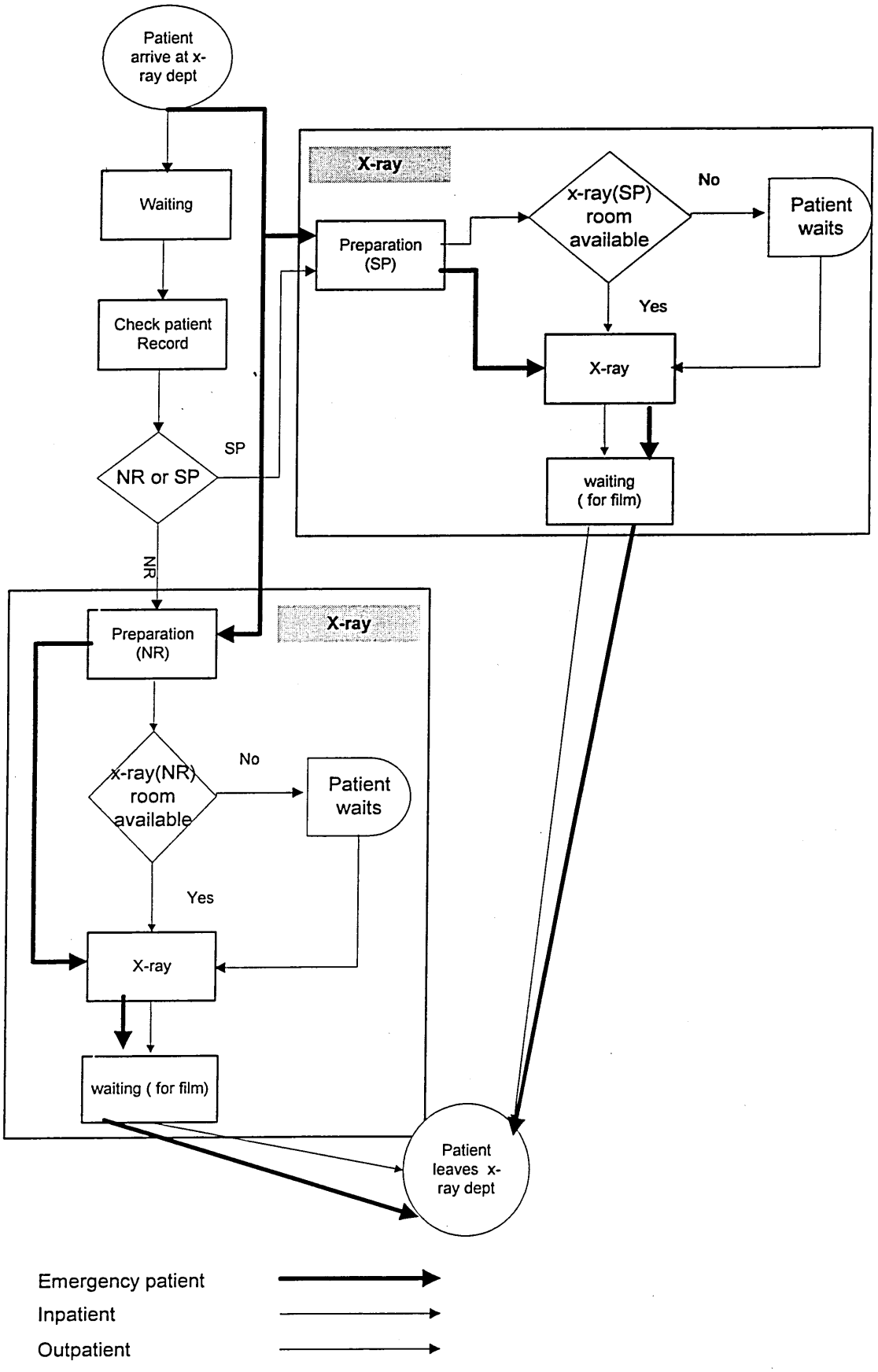
The following diagram presents the patient flow through the X-ray department. Most of the X-ray department, procedure types are divided to two major sections, Special Procedure (SP) and Neuro Procedure (NR).

The types of patients that are served by X-ray department are varying. There are three primary sources for incoming patients:

- Emergency Patient
- Indoor patient
- Out door patient

Following figure presents the patient flow through the X-ray department

Figure 9 : Patient Flow through the X-ray Department



Detail analysis of patient flow through the X-ray department

Jobs	Process	Resource	Input data (distribution/probability/time)
Emergency patient	Arrive	Technician Assistant	Arrival Time
	Assign procedure type	Technician	
	Preparation	Technician Assistant	Preparation time
	x-ray SP procedure or NR procedure	Technician Assistant	X-ray time
	Film processing	Technician	Time for film processing
	Exit		
Inpatient	Arrive .		Arrival Time
	Registration	Clerk	
	Assign procedure type	Technician	
	Preparation	Technician Assistant	Preparation time
	x-ray SP procedure or NR procedure	Technician Assistant	X-ray time
	Film processing		Time for film processing
	Exit	clerk	
Outpatient	Arrive		Arrival Time
	Registration	Clerk	
	Assign procedure type	Technician	
	Preparation	Technician Assistant	Preparation time
	x-ray SP procedure or NR procedure	Technician Assistant	X-ray time
	Film processing	Technician	Time for film processing
	Exit	clerk	

3.2 Step2: Prototype templates and specifications for the X-ray department

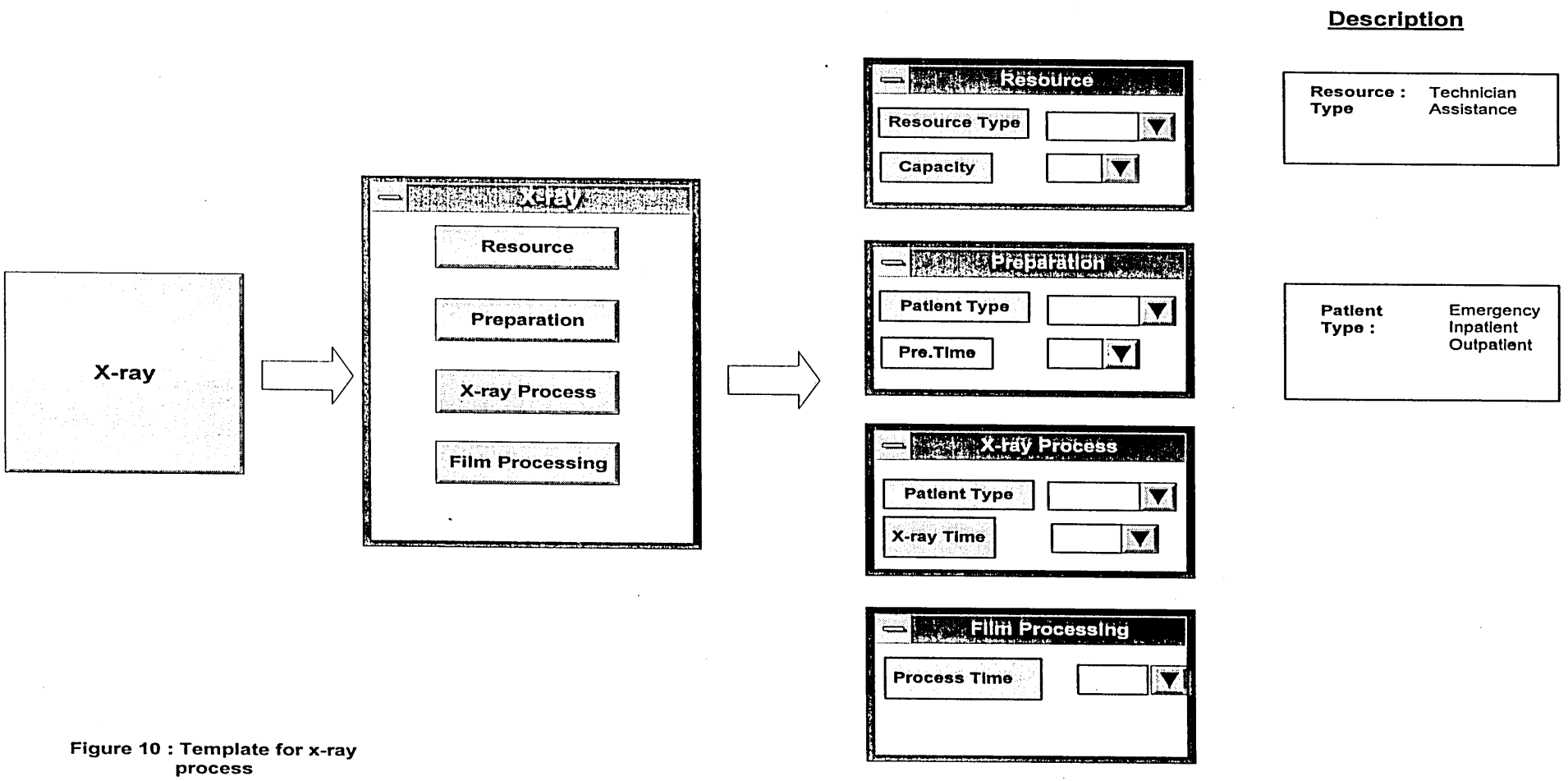


Figure 10 : Template for x-ray process

4 Area 5 : Maternity Process

In the maternity ward, there are four major sections, Antenatal clinic, Normal delivery area, emergency delivery area and postnatal ward. Normally, there are three different type of patients enter to the maternity ward.

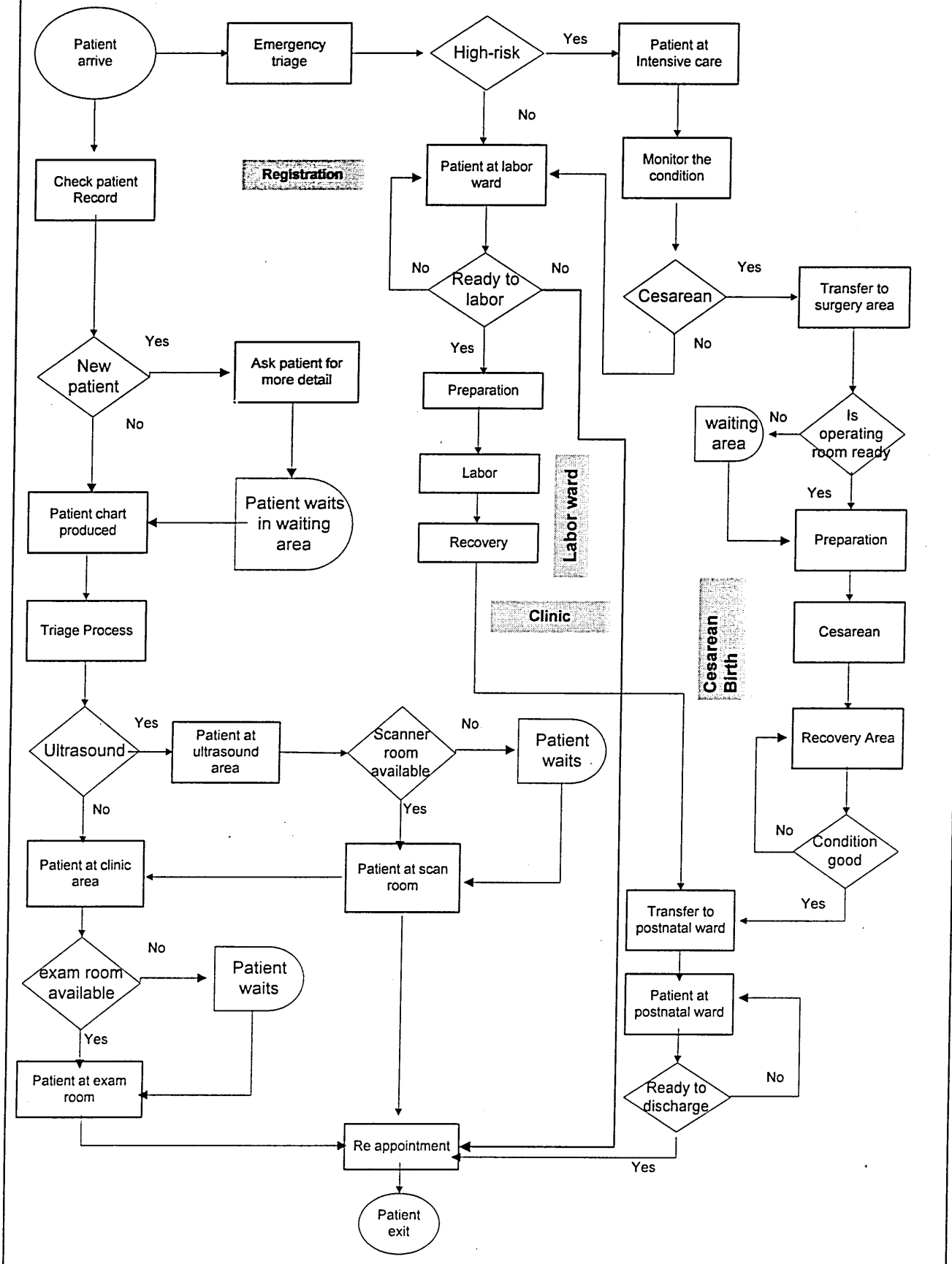
They are:

Clinic patient
Low risk patient
High risk patient

4.1 Step 1 : Analysis of patient flow through the maternity ward

The following diagram presents the patient flow through the maternity ward:

Figure 11 : Patient Flow at MaternityWard



- **Detail analysis of each steps of the above patient flow :**

Description of activity	Resource Involved	Data type (example)
Patient arrival rate		Normal (.5, .25)
Chance to enter patient for Antenatal clinic		With 0.5(probability)
Chance to enter patient for low-risk triage		With 0.3 (probability)
Chance to enter patient for high-risk triage		With 0.2 (probability)
Registration time for clinic patient	Admin Staff	Uniform (0.14, 0.54)
Triage time for clinic patient	Nurses / Assistance	Uniform (0.13, 0.45)
Examination time for clinic patient	Consultant/doctor/nurses	Uniform (0.16, 0.32)
Ultrasound exam time	Technician /Nurses	Uniform (0.15, 0.13)
Preparation time for labor	Nurse/doctor/midwife	Uniform (0.14, 0.02)
Delivery time at labor room	Nurse/doctor/midwife	Uniform (0.05, 0.02)
Intensive care time	Nurse/consultant/ doctor	Uniform (0.13, 0.12)
Pre cesarean time	Doctors/ assistants/ Technicians/nurses	Uniform (0.03, 0.02)
Cesarean time	Doctors/consultant/ nurses/assistants/ technicians	Uniform (0.04, 0.02)
Post cesarean time (Recovery area)	Nurse/doctor/midwife	Uniform (0.05, 0.03)
Patient time at postnatal ward	Nurse/doctor/midwife	Uniform (0.14, 0.12)
Time for reappointment and discharge	Admin Staff	Uniform (0.05, 0.03)

4.2 Step2 : Developing Specification and prototype templates for Maternity Process

Opportunities for sample template

- Labor ward
- Maternity Clinic
- Cesarean Birth

Prototype templates and specifications for the above places

Figure 12 : sample template For : Labor ward (see page)
Figure 13 : sample template For : Maternity Clinic (see page)
Figure 14 : sample template For : Cesarean Birth (see page).

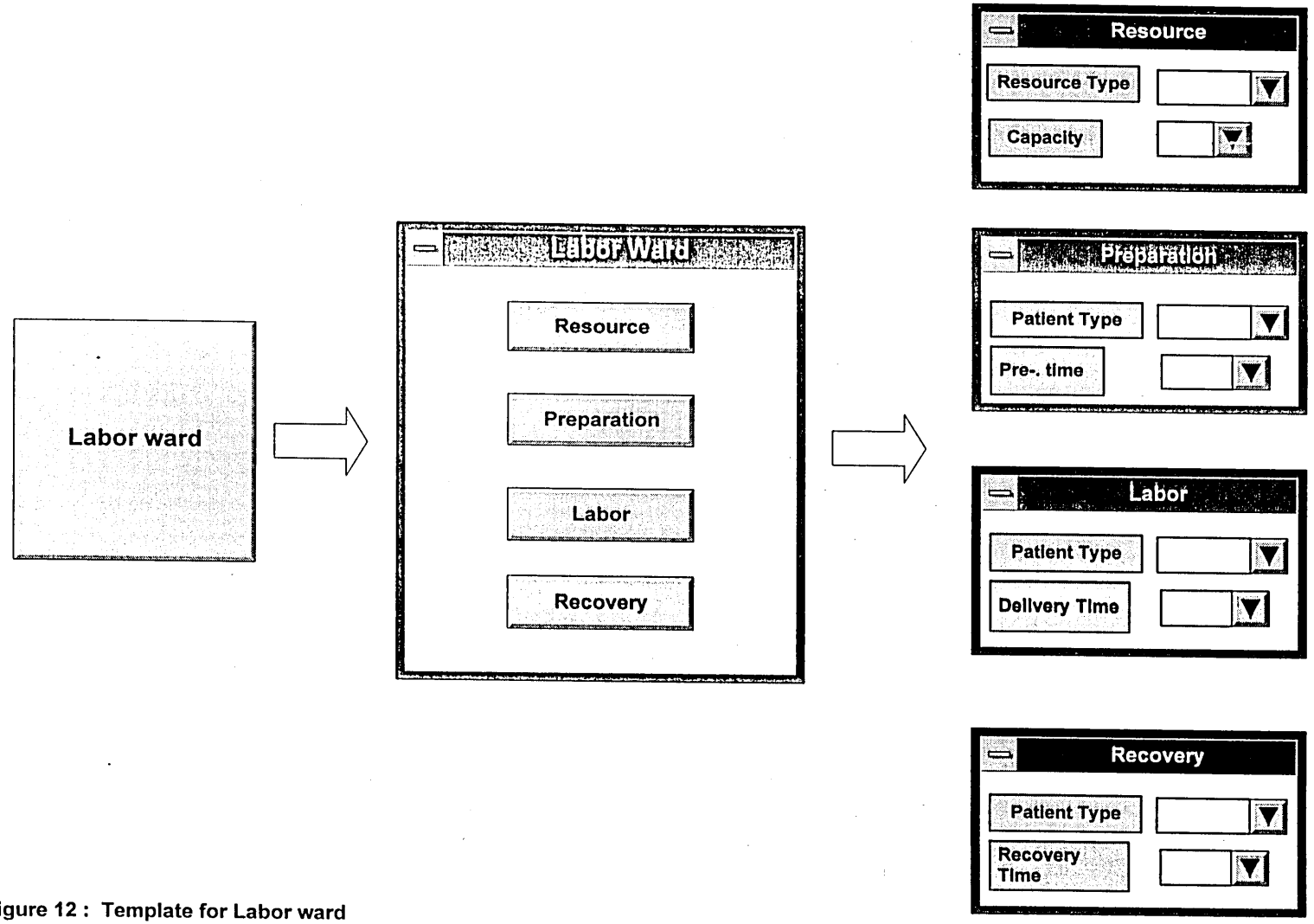


Figure 12 : Template for Labor ward

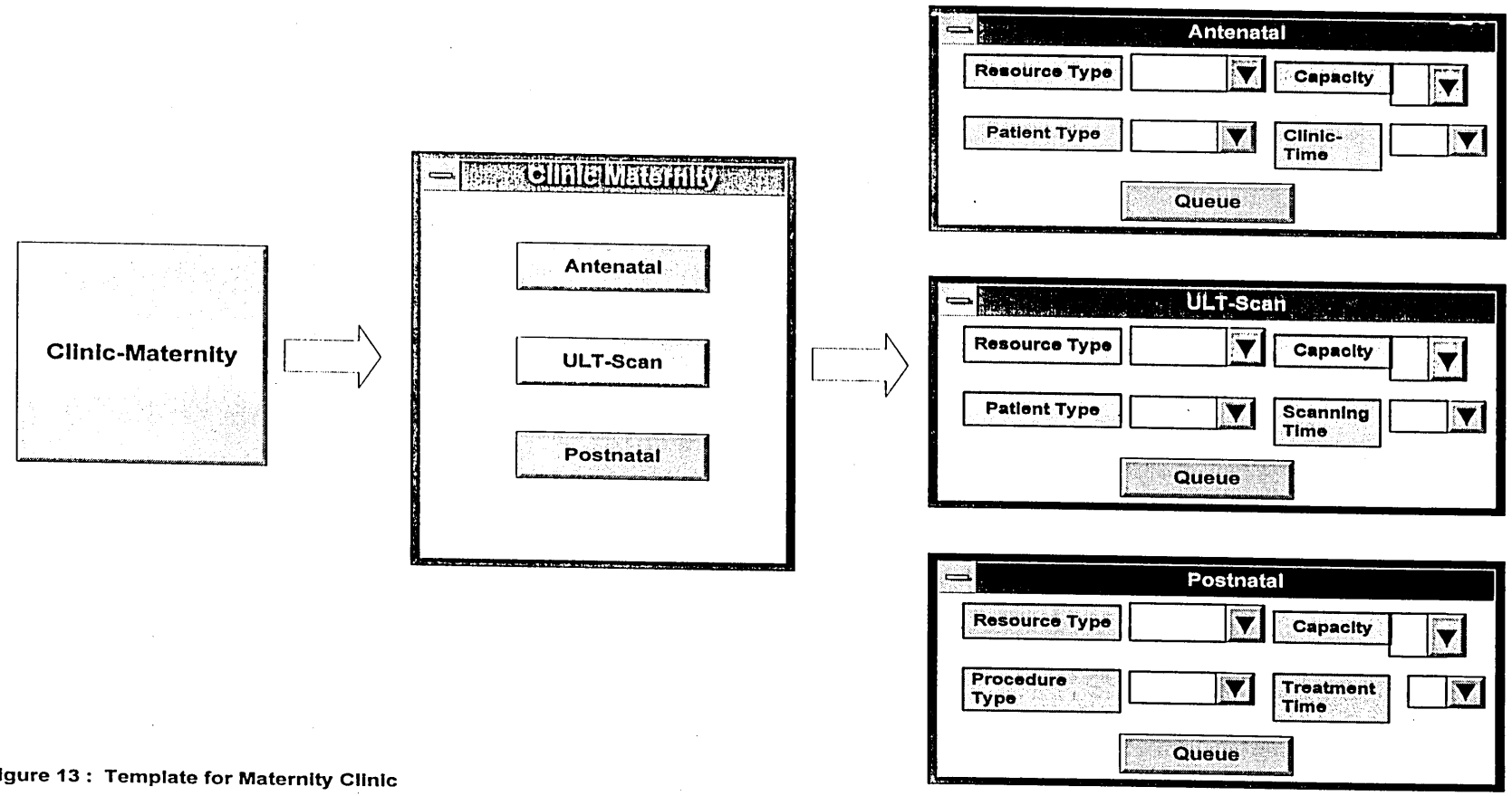


Figure 13 : Template for Maternity Clinic

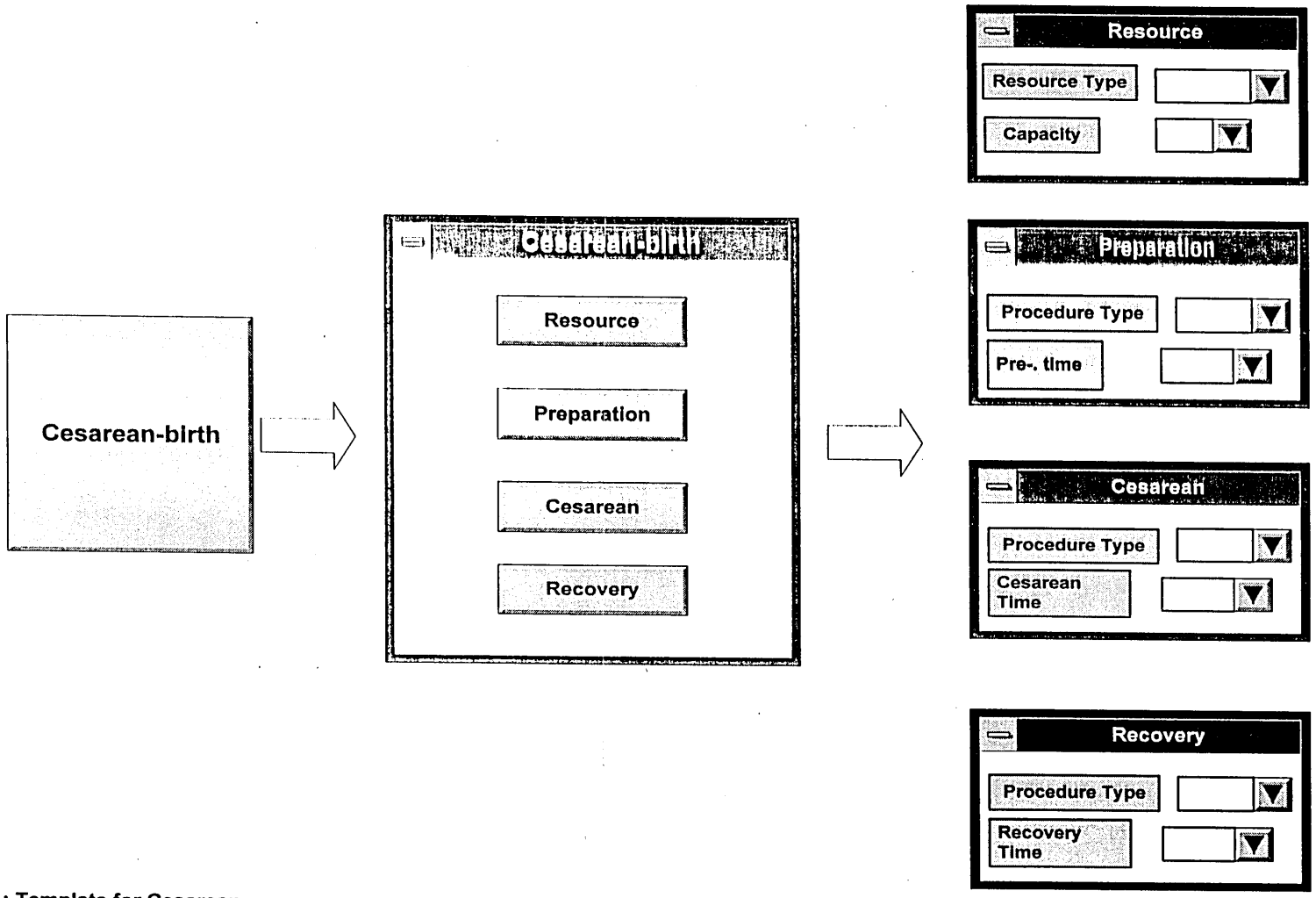


Figure 14 : Template for Cesarean birth