A Simulation-based Decision Support System to improve Healthcare Facilities Performance – elaborated on an Irish Emergency Department

By

Dipl.-Ing. Michael Thorwarth

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Supervisor: Dr. Amr Arisha, *Ph.D., MSc.*

External supervisor: Professor Paul Harper, *Ph.D., MSc.*

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0.1 Abstract

Emergency departments (EDs) are a crucial access point to the healthcare system in Ireland. High patient demand and limited resources have resulted in long waiting times and long lengths of stay in EDs. Some of this pressure on EDs could be ameliorated by more streamlined hospital processes particularly in managing discharges and managing the volume of work. This research sought to develop a simulation-based Decision Support System (DSS) to enable an accelerated development of a simulation based solution to improve quality and care at Irish hospitals.

In order to investigate causes of bottlenecks and insufficient distribution of resources, a novel process modelling approach is developed, where patient pathways are investigated in relation to the work flow of medical staff with the consideration of the dependence on limited resources. This approach is included in the simulation based DSS which aids to consult managers of EDs by providing a comprehensive perspective onto the crucial factors affecting their services and processes. To prove this novel concept of Multiple Participants Pathway Modelling (MPPM) with regard to Flexible Resource Allocation (FRA), a simulation study is applied to the ED of an academic teaching hospital in Dublin. This research is divided into primary and secondary research phases, in which the secondary – the applied field work – is guided by a combination of qualitative and quantitative research methodologies. EDs are an ideal test environment as they represent a dynamic working environment where the allocation of medical staff is flexible and tailored to current patient demand. However, exact medical procedures must still be followed. These factors are considered by the application of MPPM with regard to FRA. These complex process interactions form a holistic simulation process flow network allowing application of scenarios that impact both process flow pathways: those of patients and of medical staff.

This research makes a contribution to both theory and practice: the theory is covered by the framework which outlines the simulation based DSS, while the practical objectives are delivered by its application in the ED. The investigated scenarios offer a higher degree of confidence in the interpretation of the simulation results and provide a clearer picture of the resulting consequences of the potential introduction of certain policies.

Declaration

I certify that this thesis which I now submit for examination for the award of Doctor of Philosophy (PhD), is entirely my own work and has not been taken from the work of others, save and to the extent that such work has been cited and acknowledged within the text of my work.

This thesis was prepared according to the regulations for postgraduate study by research of the Dublin Institute of Technology and has not been submitted in whole or in part for another award in any Institute.

The work reported on in this thesis conforms to the principles and requirements of the Institute's guidelines for ethics in research.

Signature ____ Date __________________

Michael Thorwarth

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Nomenclature

AD	Absolute Deviation
ADCC	Ambulatory Day Care Centre
ADL	Activities of Daily Living
AI	Artificial Intelligence
BPD	Business Process Diagram
BPMI	Business Process Management Initiative
BPMN	Business Process Modelling Notation
CBA	Coordinated Booked Admission
CDSS	Clinical Decision Support System
CDU	Clinical Decision Unit
CP	Clinic Pathways
CT	Computed Tomography
CVS	Concurrent Version System
DMM	Data Mining Module
DNW	Did Not Wait
DoHC	Department of Health & Children
DRG	Diagnosis Related Groups
DSS	Decision Support System
ECyM	Extended Cyclomatic Metric
ED	Emergency Department
EDC	Estimated Degree of Complexity
EDSIM	Emergency Department SIMulation

EHCI	European Health Consumer Index
FiFo	First in First out
FIPS PUBS	Federal Information Processing Standards Publications
FRA	Flexible Allocation of Resources
FSM	Finite State Machines
GDP	Gross Domestic Product
GP	General Practitioner
GUI	Graphical User Interface
HIS	Hospital Information System
HSE	Health Service Executive
ICD	International Classification of Diseases
ICU	Intensive Care Unit
IDEF	Integration Definition for Function Modelling
ILP	Integer Linear Programming
KPI	Key Performance Indicator
LoS	Length of Stay
MPPM	Multiple Participant Pathway Modelling
MRU	Maximum Resource Use
NHS	National Health Service
OOP	Object Orientated Programming
PACS	Picture Archiving and Communication System
PDMS	Patient Data Management System
PDSS	Performance Decision Support System
PPP	Purchasing Power Parity
QNA	Queuing Network Analysis
RFID	Radio Frequency Identification
SD	System Dynamics
SLAM	Simulation Language for Alternative Modelling
SVUH	St. Vincent University Hospital

TQM	Total Quality Management
UBA	Uncoordinated Booked Admission
VSE	Visual Simulation Environment
WF	Work Flow
WHO	World Health Organization
ZWT	Zero Waiting Time

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Chapter 1

Introduction

"A Healthy Nation is a Wealthy Nation" (Smadu 2006, p. 1)

This strong statement is the title of a report which links together the health, productivity and wealth of a nation. This title immediately raises the question of how much money is spent on health and how an adequate distribution can be achieved. The ideal case would be that everybody receives the best treatment and care if they are unfortunate enough to be struck down by illness. However, this ideal situation would rely on many resources and require high levels of investment. An inevitable knock-on effect from this would be a lack of funds and resources elsewhere for example in education, research, and infrastructure to maintain productivity. The issues addressed here are of a political, philosophical and ethical nature - discussing productivity in this context may also appear unethical. However, the statement above highlights various issues which show that health has its price and that resources for the provision of healthcare are limited.

In addition to this limitation, healthcare systems and facilities in general are facing high demands resulting from a steadily ageing and growing population (O'Reilly & Wiley 2007, United Nations 2009) (see Figure 1.1 for the development in the EU). Improving the current system is an essential challenge to everyone involved in healthcare management.

Hospitals play an important role in the provision of healthcare and almost 33% of

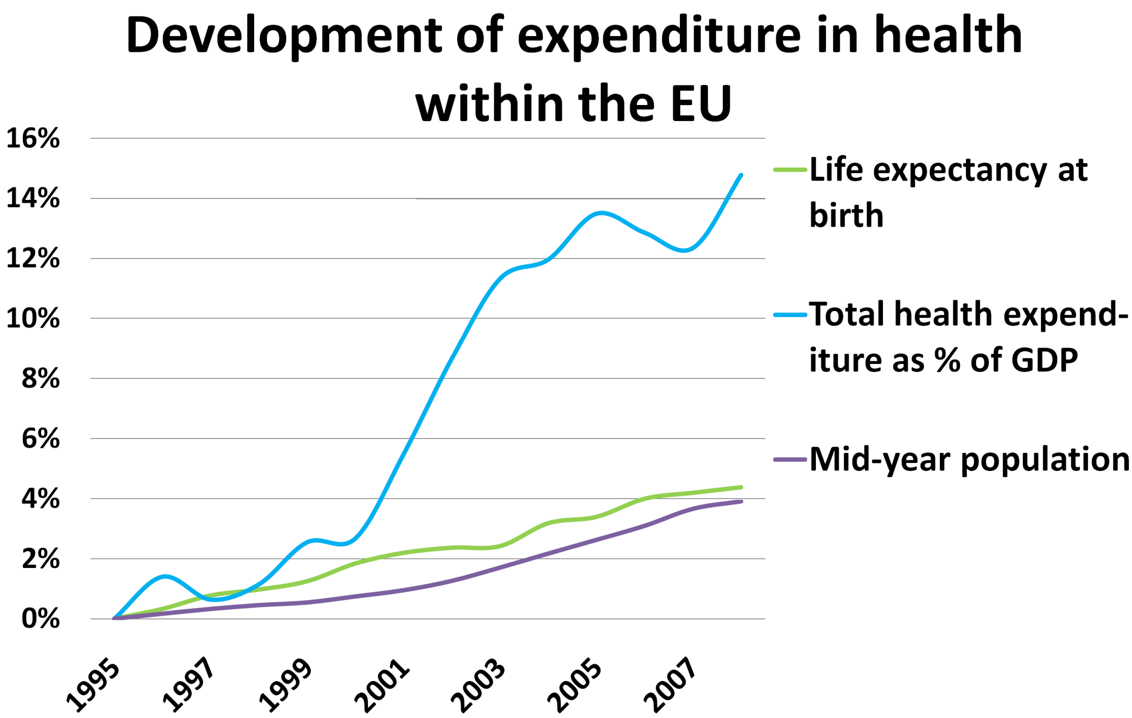


Figure 1.1: Development of the expenditure in health in comparison to the development of of age and population size (based on WHO estimates, year 1995 are referenced as 100%). *Source: World Health Organization (2010).*

health related governmental spending is dedicated to hospitals in general (Cochran & Bharti 2006*b*), while in Ireland the share of hospitals providing health is approximately 45% (Department of Health & Children (DoHC) 2007). The majority of hospitals in Ireland are public and are largely funded from public healthcare sector sources. Hence, patients have a citizen's right to a satisfactory quality of service. Indeed, the success of hospital management hinges crucially on customer satisfaction and demand.

Management of Irish healthcare systems – in particular hospitals – are constantly striving to meet customer requirements, but must manage within the constraints of limited resources and increasing demand. This presents the need to find effective ways of resource allocation (Proctor 1996). It is believed that one of the essential problems which the authorities must effectively handle is how to optimise the use of the available resources with a view to achieving the targeted performance (Carter 2002).

Healthcare providers and suppliers therefore aim for efficient solutions to continue to provide their services. Hospitals play an important role as a healthcare provider: medical care, surgical operations, diagnosis, and acute care are the key missions, of which all share common resources like for example diagnosis devices, treatment rooms, and waiting rooms. In order to provide their services as efficiently as possible, it is in the interest of the hospital managers to allocate resources according to the patient demand. Undersupply of resources results in long waiting times, extended Length of Stay (LoS), complications for the patient and even death is likely. In addition, an oversupply results in high costs, which endangers the provision of the adequate healthcare service.

To improve efficiency with regard to healthcare facilities, several measures can be implemented ranging from Diagnostic Related Groups (DRG); a measure which demands a sophisticated Hospital Information System (HIS) on one side (Jänicke & Müller-Lazarewski 2009). This measure also offers new improvement measures that are accessible via additional features such as PACS (Picture Archiving and Communication System) which allow the transfer of diagnosis images hospital wide within seconds and allows bedside consultations (Sainfort et al. 2005). To coordinate these improvements and to manage the vast amount of data, clinical pathways – defined by process management methods – coordinate the flow of patients through the system. By identifying clinical pathways, additional improvement opportunities arise. With the implementation of HIS and PACS, thorough data management is essential in hospitals and opens a wide range of opportunities to improve the current system which inherits a wide range of resources and services for their patients.

1.1 Problem Definition

The major cost drivers in healthcare are the knowledge intensive services which are staff intensive (compare annual report of Dublin clinic group, where salaries and wages were 63% of the annual expenditure in 2007 (St. Vincent's Healthcare Group Limited 2007, p. 26)). The tasks of the staff are of a medical, technical, administrative and logistic nature. Those categories are intersecting disciplines and staff must be multidisciplinary educated in order to provide the newest available diagnostic and therapy technology to their patients, and also be knowledgeable about the latest developments in healthcare (Strayer et al. 2010). Logistical tasks such as bedding, cleaning, and catering are among the duties which must be accomplished for the wellbeing of patients. As the level of salary and wages differs highly it is important that resources are allocated adequately with the consideration of cost efficiency. These categories are typical for healthcare facilities and also applicable to smaller hospitals or to smaller healthcare facilities.

Healthcare in general is additionally under high pressure as the demand steadily increases with the growing and ageing population (Figure 1.1). This increased demand urges healthcare managers to seek solutions in managing staff capacity under budget constraints. These solutions can be found by considering an improved process flow with supportive information systems, by allocating resources adequately to the job type, and scheduling staff to match demand. The latter shows a gap between demand and service provision which is getting wider with the current economic condition and supply will not be able to close that gap.

In Ireland, the body responsible for the provision of health is the HSE, which was established by the Health Act, 2004 as the successor of the ten regional Health Boards. Its aim is to modernise and improve the distribution of healthcare services among the Irish population. HSE plays an instrumental role in securing "access" of the Irish people to the healthcare services and also to monitor and maintain high quality standard of healthcare delivery. Regular targets and reports provide a certain level of transparency which helps to enhance its delivery. HSE performance began slow in terms of achievements and this is clearly reflected in the results of European Health Consumer Index (EHCI) report in 2005 ranked Ireland 25th among 26 investigated European countries (Health Consumer Powerhouse 2006). Improvements followed soon and in the next issued report in 2006, Ireland ranked 16th among 28 countries (Health Consumer Powerhouse 2007). This prompted the Health Consumer Powerhouse to make the following comment:

> *"The Health Service Executive reform seems to have started improving an historically dismal performance. Still severe waiting list problems and less than fantastic outcomes."*, (Health Consumer Powerhouse 2007, p. 24)

The recent EHCI report in 2008 ranked Ireland as 15th out of 31 ranked countries (Health Consumer Powerhouse 2009), while the expenditure of the Irish is among the first quartile among the European countries with $3676 of their purchasing power parity (PPP) per capita. Considering this relatively high annual expenditure in health, the 15th rank is a disappointing outcome, especially when the 1st ranked Netherlands only spends $73 more than the Irish population (World Health Organization 2010). A comparison of some selected countries with their expenditure and ranking outcome is provided in Table 1.1. Looking at the ranking criteria within the EHCI report, Ireland seems to score above average on medical outcome and on pharmaceutical criteria, whereas they score below average in waiting times and information provision for patients. Hence, it is apparent that there is significant room for improvement in the operation and tactical levels.

Given the fact that most – if not all – of the Irish hospitals operate on the verge of their capacity limits, waiting lists represent a critical issue to the public and equally to hospital management. One of the departments which is exposed to an extreme pressure due to capacity limits of the hospitals is the ED as these are attached to the hospitals and commonly share resources.

In general EDs primary mission is to provide acute care for severe and emergent cases, where alternatives (e.g. General Practitioner (GP) or other primary care) are not available. Department of Health & Children (DoHC) (2001) lists the prin-

Table 1.1: Total expenditure on health per purchase power parity (PPP) in Dollar – WHO estimates (World Health Organization 2010) – and as percentage of gross domestic product (GDP) compared with the ranking outcome of the EHCI for the year 2008 (Health Consumer Powerhouse 2009).

Country (2008)	Total health expenditure PPP$ per capita	Total health expenditure as % of GDP	Ranked by EHCI
Netherlands	3749	9.9	1
Ireland	3676	8.7	15
Denmark	3630	-	2
United Kingdom	3230	8.7	13
European Union	2878	9.2	-
Italy	2825	9.1	16

cipal issues of the current primary care and provides reasons for its inavailability. Hereby it is highlighted that the primary care infrastructure and capacity is poorly develeoped and that the potential to reduce pressure on secondary care are not fully realised (Department of Health & Children (DoHC) 2001, p. 17). Due to the underdeveloped primary care the in Ireland, the EDs are usually characterised as:

1. Demand driven unit;
2. Highly dynamic environment;
3. Most patients who arrive at the ED require immediate service and attention which creates extra pressure on staff;
4. Critical decisions have to be made with a high level of reliability and accuracy;
5. Diversity in range of medical services provided by the unit;
6. High level of uncertainty (i.e. one can never anticipate the casualty coming next);
7. Information retrieval is essential. Updating and upgrading systems in the unit can save lives;

8. Most of the EDs have limited resources and issues in assigning the optimal staff required.

Therefore planning and management of EDs represent a challenge. Many attempts in different countries have aimed to alleviate some of the issues related to ED performance. For example the employment of emergency GPs after GP opening hours provides some relief to the demand of the ED. Such a scheme is also in place in Ireland, but is largely unknown to the public and therefore patients seek attention from their nearest ED. EDs in Ireland therefore are facing a high demand (Regan 2000) and as a resulting side effect EDs struggle to provide adequate service and consequently to provide the satisfactory service level. The Health Service Executive (HSE) (2007) states in their Emergency Task Force Report that: "At least 7 of the Emergency Departments are unfit for purpose.", (Health Service Executive (HSE) 2007, p. 10). Some of the reasons addressed in the HSE report are due to high variations in:

- Bed capacity;
- The availability and quality level of clinical decision-making;
- The accessibility of diagnostics, senior in-house speciality assessment and other ED supports;
- Internal control processes;
- Community and continuing care capacity and processes.

In addition, EDs in Ireland are highly criticised by the public due to long waiting times of patients. However, it is fair to say that the staff utilisation in EDs reaches unbearable limits (95 - 99%) with stressful conditions. As a result, the nurses went on a strike in 2007 for eight weeks in order to improve their working conditions. This strike has shown gaps in planning and management of the unit and has highlighted more hidden issues on the operation level.

1.2 Research Motive

Demands on the health services continue to grow and increasing healthcare costs are a reality which the Irish healthcare system addressed by undergoing rapid change (Department of Health & Children (DoHC) 2007). Healthcare providers and suppliers therefore aim for efficient solutions to continue to provide their services.

EDs are considered as gatekeepers for the hospital system. The highlighting of problems with long waiting lists and overcrowded Irish EDs have shown that the system currently in place cannot meet the demands placed on it (Lynch 2004). EDs in hospitals all over the world face similar difficulties in terms of long waiting times, staff resourcing problems, and capacity limitations (Brailsford et al. 2006). There are three factors which must be considered and predicted by management for effective capacity planning: how many patients arrive, at what rate, and how long will the service take (Fottler & Ford 2002)? These factors include a significant degree of uncertainty, which should be kept as low as possible for efficient planning and forecasting. Another source of uncertainty is the change of the distribution of the patient-mix over time. Patient-mix is affected by the local placement of the ED and seasonal changes; for example, a higher patient demand is identified to be related to the cold seasons (Vasilakis & El-Darzi 2001).

The Irish Situation

Evidence of the severe state of Irish EDs is manifested in academic papers, official reports issued by HSE, Health Consumer Powerhouse AB and current media. It is shown that the current state of the Irish EDs is in a severe condition with long waiting times, unnecessary delays and blocked admissions. The Emergency Task Force Report (Health Service Executive (HSE) 2007), for example, points out that 7 out of 21 surveyed EDs failed to deliver their service in 2006.

To identify the problems with the Irish healthcare system, several sources are consulted: firstly, academic papers which report long waiting and admission times (Regan 2000, Nolan & Nolan 2005, McDermott et al. 2002), secondly official reports (for example provided by HSE) displaying the need for action (Department of Health & Children (DoHC) 2001, Health Service Executive (HSE) 2007, The Irish Society for Quality and Safety in Healthcare, Royal College of Surgeons in Ireland and Ipsos MORI Ireland 2007, HSE 2007, Health Consumer Powerhouse 2009), and thirdly, current media revealing public disappointment in the healthcare service (Wall 2008*b*, RTE RADIO 1 2007). Following the European Health Consumer Index in (Health Consumer Powerhouse 2006) and (Health Consumer Powerhouse 2007), it can be seen that the Irish healthcare system is not performing well: a change in the ranking scheme lifted the Irish healthcare system from 25th out of 26 countries (based on findings in 2005) to 16th out of 29 countries (based on findings in 2006), but Health Consumer Powerhouse (2007) conclude that the HSE has achieved improvements on the overall performance, but issues remain apparent which address the waiting list and the treatment outcomes.

In June 2007 the HSE reported the following indicators which emphasise the severe conditions. These were stated in the Emergency Task Force Report (Health Service Executive (HSE) 2007):

- EDs in Dublin operate at a utilisation level of between 95% and 99%;
- Long admission times to ward: 57% of all patients wait longer than 6 hours and some (39%) wait longer than 12 hours.

Another official HSE report describes further need for action by stating that 35% of patients have to wait more than half an hour to be triaged and 60% of patients usually waited longer than an hour to be seen by a doctor in the ED (The Irish Society for Quality and Safety in Healthcare, Royal College of Surgeons in Ireland and Ipsos MORI Ireland 2007). The wait for treatment in six investigated Dublin EDs was 6.5 hours in average (Regan 2000). These waiting times do not consider prioritised patients with severe conditions who may have quicker access to service than the average patient.

The Irish EDs play an important part in the provision of primary care in Ireland, considering the high self referral rate (The Irish Society for Quality and Safety in Healthcare, Royal College of Surgeons in Ireland and Ipsos MORI Ireland 2007). Access to the service within EDs is congested and the internal processes experience various types of delay: diagnosis not available on time, doctors and nurses busy with other patients and missing documents (Regan 2000). A recent statement by a consultant in an Irish ED suggests that the state of Dublin EDs remains severe:

> *"Emergency departments have an extremely important function and compromising the ability of the staff and units to perform it by allowing them to be dangerously overcrowded is potentially life threatening and absolutely unacceptable."*, see (Gilligan 2007, Dr. Peadar Gilligan, Consultant in Emergency Medicine, Beaumount Hospital, Letter to the Editor, Irish Times, 26 February 2007.)

A combination of the three features: high utilisation of resources, long waiting time for service, and diversion of ambulance admission, leads to the description of the status of an ED as "overcrowding". The mortality rate due to overcrowding in the ED can be as high as 30% based on a study of Australian EDs (Richardson 2006, Sprivulis et al. 2006). EDs in Dublin can be described as overcrowded and the health service deliveries are far from their optimal settings with long patient waiting times for treatment, delays of treatments, and a high occupancy level (Health Service Executive (HSE) 2007). The findings of the above sources are backed up with the findings of our current research, conducted at a large academic teaching hospital (cf. Section 3.3.3 on Page 128).

Long patient waiting times are not only uncomfortable and in some circumstances painful to the patient, but the longer the patient waits, the more severe the situation for the patient can become, which hence, again results in longer treatment times:

> *"Patients are harmed in the process of delay, not only through wasted time, but through unnecessary suffering, and through adverse medical outcomes. Health care providers are harmed through the added cost and reduced efficiency resulting from the complications of handling delayed patients. For these reasons, it is imperative for all providers to seek out and implement solutions that reduce delay."*, (Hall & Connelly 2006, p. 3)

To improve the current situation, the HSE has introduced targets especially for EDs in which it is demanded that any patient should not stay for longer than 6 hours in between the first registration until their release (Buckley 2009, p. 10). This target therefore aims for the LoS to not exceed 6 hours, and thus – strictly speaking – no patients record should exceed this limit.

Due to the findings regarding Irish healthcare issues, it becomes apparent that capacity planning is a key element to effectively manage the process within EDs. Identifying the demand is an essential step to planning the required resources (short-term / long-term) that facilitate thorough utilisation of capacity as well as a smooth and uninterrupted flow of patients through the system. Errors in forecasting for capacity planning have an immediate impact on the service quality level. However, considering the dynamic environment of an ED, the decision making is very challenging, especially regarding scheduling decisions to allocate resources in a demand-driven environment. The high variability of demand increases the challenge for decision makers. In order to resolve this issue, it is essential that transparency of the system is available and that information is available when it is needed. Information, such as patient data, allows the investigation of bottlenecks and constraints of the system, and thus provides a basis for sound supported decisions. A system based on replications and analysis of the past events thus would provide insight into the mechanism of the system and provide opportunities to state "What-If"-Questions.

1.3 Aim and Objectives

Aim:

> To develop a Simulation based Decision Support System (DSS) which enables an accelerated development of a simulation based solution in order to improve quality and care at Irish hospitals. The DSS has to be flexible to accommodate various healthcare factors.

Objectives

The following objectives were set to be achieved in this project and in order to achieve the above stated main aim:

- To examine current practices in A & E department in order to address different sources of variability within the department;
- To develop or adopt a comprehensive modelling technique to help in capturing the dynamics of the system under investigation;
- To construct ready-modules into a library form in order to speed the modelling process;
- To define bottlenecks and system constraints in order to develop corrective actions (i.e. strategies and plans);
- To develop an optimisation capability to be integrated into the DSS for better decisions such as stochastic uncertain environments.

The main aim and the objectives hence overall, provide a DSS which helps decision makers in finding solutions on a sound information basis. It is therefore the aim to provide a comprehensive DSS that delivers a novel detailed approach whilst respecting the complexity and dynamics of healthcare systems and facilitates other researchers and modellers to widen the potential of integrated solution methods.

1.4 Thesis Outline

This thesis consists of seven main chapters and five appendices.

Chapter two covers the literature review where other approaches are investigated and complexity issues are addressed.

Chapter three contains discussion regarding the research methodologies which are applicable and highlights the research methodology that is used for the design and the application of the DSS.

Chapter four describes the design of the DSS, the development of the modules and the application fields.

Chapter five documents the application of the designed DSS in the ED of the St. Vincent University Hospital by providing simulation experiments.

Chapter six yields the discussion where the results of the previous two chapters are discussed.

Chapter seven concludes this thesis with a comprehensive view of the delivered results and objectives. This conclusion delivers recommendations for future work.

The appendices comprise the following:

- DVD containing source code, model and data
- Instructions to apply for data processing
- Description on process modelling techniques
- Additional information for optimisation
- Complete IDEF0 process map of the SVUH ED

Chapter 2

Literature Review

Ageing and growing populations cause a steady increase in total costs for healthcare. Every five years, an increase of approximately 1% of the fraction of healthcare costs of the gross domestic product (GDP) is observed in the developed countries (World Health Organization 2008). Within the Euro zone for example 9% of the GDP in 2007 was spent on health. In order to slow down this trend, healthcare professionals and researchers are charged with finding new methodologies to manage operations within healthcare as well as efficiently managing the provision of this healthcare.

This chapter introduces the issues that are of primary concern within healthcare, starting with a broad overview before concentrating more specifically on problems regarding Irish emergency departments (EDs). The complexity of healthcare as well as the measurements in place are addressed in the next subsection in the context of process simulation. This is followed by an overview of application examples. Optimisation will then be investigated as well as how it is integrated into healthcare simulation models and how it can contribute to providing solutions. A discussion section focusing on the identified gaps in the literature concludes the review chapter. As an early revelation, it can be indicated that the identified gaps cover topics that merge complexity consideration, process modelling, model generalisation, and dynamics of the healthcare services (Section 2.5.2 on Page 107).

Figure 2.1 provides an overview of the presented literature review and the topics to be addressed. The topic boxes which overlap the literature review box indicate

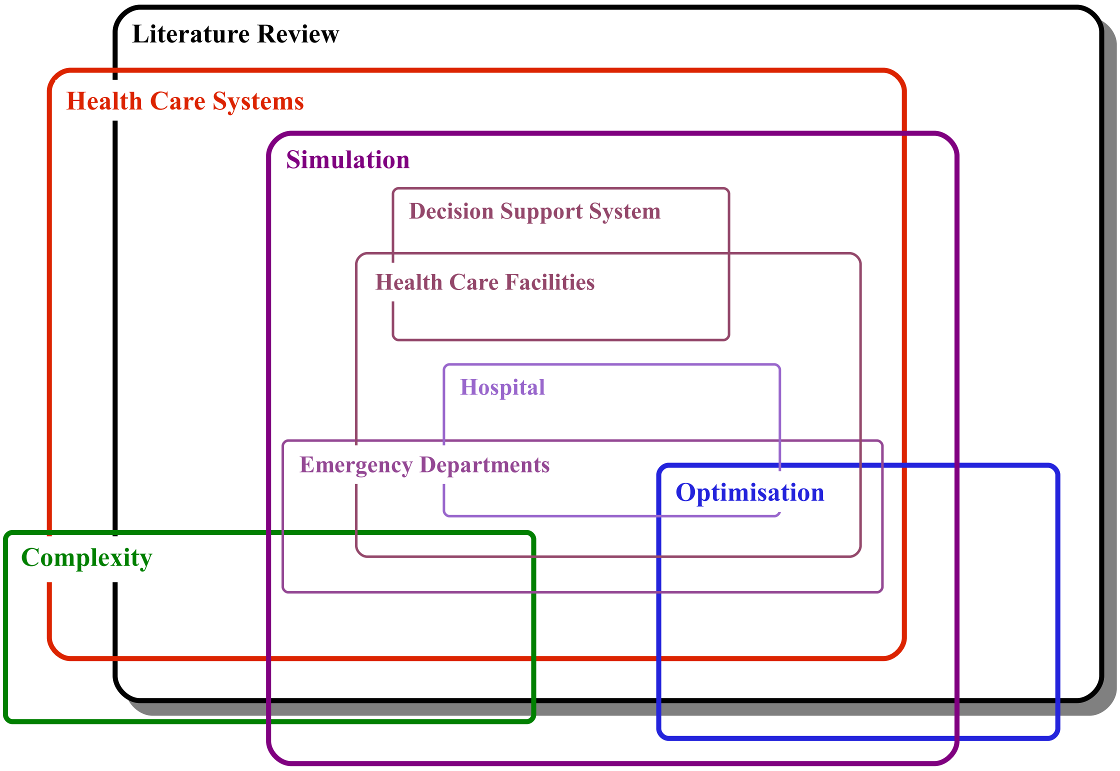


Figure 2.1: Topic Overview of the Literature Review.

that there is literature which cannot be presented here due to the capacity limitations of this dissertation.

2.1 Healthcare Systems

Ever since societies introduced the division of labour, care for those with key skills has been a crucial element within sustainable civilisations. Medical care and sophisticated healthcare treatments such as spine surgery date back to the ancient Egyptians and Babylonians (Goodrich 2004). Within these ancient civilisations such healthcare would not be available for all members of the society and would be limited to the wealthy or important citizens. Throughout the development of societies, healthcare distribution has attracted a great deal of public interest. As a result healthcare was administered more widely through churches as an act of caritas – the origin of the word "charity" – as it could be seen by medieval Christian monasteries (Agrimi & Crisciani 1998). The lengthy transformation of such medieval healthcare systems to the now modern supply and distribution of healthcare is described by Crislip (2005).

Health is a special good, which is intangible and scarce. The economic relationships arising from this special context for the provision of healthcare are described in detail by Folland et al. (2009) who illustrate the planning and organisation of potential systems from an economic standpoint. Funding and financing the distribution of healthcare is an important aspect for all societies. Finding the optimum ration of GDP spent on health is a matter which is under constant assessment and is the subject of a political debate among health providers, receivers and sponsors (Aaron 2003). However, in the special case of the Irish population, the value of provision of acute care as a service has been identivied as their right to access the healthcare system by the public (Amnesty International Ireland 2011).

There are various methods which facilitate the distribution of healthcare services such as governmental supervision, private market participants or a mixture of both. A recipient of healthcare services may receive their treatment free of charge or may have to make a full or capped payment. As health is a scarce good which is expensive to provide, the funding must be organised in a sustainable manner. Governments supervising funding refinance their costs via mandatory taxes and also allow private or public insurance schemes. These insurance schemes can be either voluntary as in the United States or mandatory as in Switzerland or Germany. In practice, the public sector dominates when it comes to financing healthcare with the private sector occupying the role of complementary provider (Docteur & Oxley 2003).

2.1.1 General Healthcare Issues

Health is a special good; it cannot be produced in an industrial sense, nor can it be guaranteed by the providers. The successful delivery is dependent on the people who are distributing healthcare. For its accomplishment, the staff involved must to be educated, knowledgeable and trained for this particular purpose. The education and training of healthcare staff is costly and furthermore they must be equipped with the right technical equipment, pharmaceuticals, and knowledge so that they can distribute healthcare to the best of their ability.

In order to maintain a sustainable healthcare system, the spiralling costs must be covered by society. Several models for the coverage of costs are applicable, however not all are equally applicable to every cultural background. However fair the attempts are to distribute the cost of healthcare, issues constantly arise which must be considered – many involving healthcare insurance and financing healthcare. One issue is that if insurance is volunteer based, then individuals with health risks are more likely to get insured than those who are in good health. As a result of this, the ability of healthcare insurance to pool financial risk and to promote access to healthcare services is limited. In some cases an "adverse selection" can occur, which results in limited access for higher-risk individuals, lower coverage and underconsumption of healthcare services for several social groups (Docteur & Oxley 2003).

Another healthcare consumption issue is that individuals may tend to consume service beyond the social optimum. It is certainly a challenge for societies to responsibly educate potential patients – or "customers" – so that health costs can be kept to a minimum. In this context it is worth evaluating prevention measures as a way of avoiding costs. There are a number of measures for the prevention of "modern diseases" in industrialised countries. These measures include educating people so that they make responsible life choices concerning tobacco consumption, obesity, physical activity and diet plans (Sassi 2010).

Concerning the true need and scope of treatment, healthcare providers often find that they are better informed than the patient or insurer. This advantage of knowledge in the "information asymmetry" may be used to trigger the demand for treatment (Docteur & Oxley 2003). Accessing this advantage would be ethically and morally questionable; two very constraining factors.

Prevention is identified as a valuable measure to lower the impact of chronic diseases on a long term basis (OECD Health Ministerial Meeting 2010). However, unless the education of people begins to have a significant impact, the demand for healthcare rises due to unhealthy diets, tobacco consumption and lack of physical activity. It is thought that these causes will trigger a significant rise in disability caused by unhealthy living: "In ten European countries, the odds of disability, defined as a limitation in activities of daily living (ADL), are nearly twice as large among the obese as in normal weight persons" (Sassi 2010, p. 15).

Demands on the health services continue to grow and increasing healthcare costs are a reality which the Irish healthcare system is currently addressing through immediate and rapid change (Department of Health & Children (DoHC) 2007). Healthcare providers and suppliers are therefore attempting to find efficient solutions in order to continue to provide their services and maintain healthcare service on a sustainable level. Indeed healthcare management may decide to save expenses and cut costs as much as possible, but at a certain point these measures become ineffective and incredibly dangerous for the patients as they lower the quality of care. In order to maintain the quality of care, decision makers look elsewhere to solve their problems, and acknowledge solutions applied and approved in the industrial sector.

2.1.2 Role of Hospitals

Publicly funded acute hospitals are a large cost factor to the economy, with approximately one third of the healthcare expenditure being dedicated to them (Cochran & Bharti 2006*b*). However, hospitals fulfil a key role in the provision of health: dependent on size and mission, they comprise several units to provide general healthcare, diagnostics, treatments, and medical care. Among several others, the main units are surgeries, Intensive Care Units (ICUs), and EDs. Beside its primary treatment and care mission, the hospital must ensure a level of hospitality for their patients, which includes accommodation and catering for the patient. As hospital beds are essential for the accommodation of patients, the size of hospitals is indicated by the number of beds provided. The hospital bed itself was treated as a cost factor within the hospital for a long while until the introduction of the International Classifcation of Diseases (ICD), which contributes costs to the treatment of the categorised disease classification (World Health Organization (WHO) 2010). From the perspective of process flow modelling, the number of hospital beds is thus a key element when it comes to analysing and forecasting capacity. Despite capacity planning efforts, a surplus of demand, leading to an increase in waiting lists, is sometimes inevitable. The longer the waiting lists, the less the provision of necessary treatment can be guaranteed to the local community. The ideal situation for the patient would be not having to wait for a treatment; this however would result in low occupancy rates and in high costs for the care provider (Vissers et al. 2007). Finding the optimum trade off between capacity usage and patient demand is a crucial task for the healthcare provider.

Reports on the development of bed usage show that hospitals in the OECD countries tend to decrease bed capacity by increasing the inpatient activity. This measure has a significant impact on day cases where the patients are treated ambulant. The positive effects of this are that patients who have day surgery experience an overall better experience, with improved clinical outcomes and a reduced risk of hospital acquired infection rate (NHS Modernisation Agency 2004). Reductions of bed numbers were about 15% (median based) among the OECD countries between 1995 and 2005, while Ireland maintained their hospital capacity and service level (OECD 2006). Estimates highlight that "338,000 more Irish patients could be treated as day cases if Ireland performed as Canada" (HSE 2007, p. 60).

Hospitals play a key role as a healthcare provider: medical care, surgical operations, diagnosis, and acute care are the key missions, of which all share common resources such as diagnosis devices, treatment rooms, and waiting rooms. In order to provide their services as efficiently as possible, it is in the interest of the hospital managers to keep the ratio of uncertain patient arrival to elective patients, as low as possible. Hospitals usually operate with a limited number of specially skilled resources and activities (e.g., physicians, nurses, and radiology tests). As a result, processes in the hospitals tend to include many hand-off 's so that all patients have access to these resources. These hand-off 's generate process delays, longer patient cycle time, and higher Length of Stay (LoS) (Bale & Krohn 2000). Most time spent in the hospital is non-value added time, such as waiting in queues. This problem can get worse with high arrival rates of patients attending the ED (Miller et al. 2003).

2.1.3 Challenges in Emergency Departments

EDs are considered as gatekeepers for the hospital system. Problems with long waiting lists and overcrowded Irish EDs have shown that the system currently in place cannot meet the demands placed on it (Lynch 2004). EDs in hospitals all over the world face similar difficulties in terms of long waiting times, staff resourcing problems, and capacity limitations (Brailsford et al. 2006). There are three factors which must be considered and predicted by management for effective capacity planning: how many patients arrive, at what rate, and how long the service will take ((Fottler & Ford 2002). These factors carry with them a significant degree of uncertainty, which should be kept as low as possible for efficient planning and forecasting. Another source of uncertainty is the change of the distribution of the patient-mix over time. Patient-mix is affected by the local placement of the ED and seasonal changes; for example, a higher patient demand is related to the cold seasons (Vasilakis & El-Darzi 2001).

Capacity planning definition is thus a key element to effectively manage the process within ED. Identifying the demand is an essential step to obtain the required resources (short-term / long-term) which facilitate thorough utilisation of capacity as well as a smooth uninterrupted flow of patients through the system. Errors in forecasting for capacity planning have an immediate impact on the service quality level, for example; elderly people – previously served in community service centres – may have to stay overnight in EDs (McDermott et al. 2002).

2.1.4 Issues in Irish Emergency Departments

The severe state of the Irish EDs is described in many sources, such as academic papers, official reports (launched by HSE), and current media, all of which highlight the need for a change of the current system:

> *"...,this system is totally unsustainable for our children, were running a health service at the moment that should be running at a far lesser cost than other countries in the developed world with much older populations."*
> (RTE RADIO 1 2007, transcript on page 4)

The former HSE chief executive Professor Brendan Drumm addresses issues concerning the relatively high costs in comparison to other countries which are performing better at the same cost level, for instance Netherlands or Denmark. These countries have a similar expenditure on health (compare Table 1.1 on page 19) as Ireland while their performance ranking is the best among Europe. In contrast, Ireland is ranked just above average (Health Consumer Powerhouse 2007). This statistic can be attributed to waiting lists and overall healthcare treatment outcome. The expenditure on health per capita in the year 2005 was \$3,125.- which is 21 percent higher than the European average (World Health Organization 2008). Nolan & Nolan (2005) support this finding by comparing OECD data with the performance indicators of other countries.

Friction points for Ireland's dismal performance are typical access points for the public, to whom the primary care is dedicated and are thus open for public discussion and assessment (Wall 2008*a*). As a part of the primary care EDs are one of the most frequently used access points for gaining access to the Irish healthcare system

(The Irish Society for Quality and Safety in Healthcare, Royal College of Surgeons in Ireland and Ipsos MORI Ireland 2007). Long waiting times, unnecessary delays and blocked admissions have been identified by Regan (2000) where the average waiting time for Irish EDs was 6.5 hours in the year 1999. For the year 2006 the HSE established that 5 percent of patients had to wait more than half an hour to be triaged and 60 percent of patients usually waited longer than an hour to be seen by a doctor in ED (The Irish Society for Quality and Safety in Healthcare, Royal College of Surgeons in Ireland and Ipsos MORI Ireland 2007). Based on similar results, the Emergency Task Force Report (Health Service Executive (HSE) 2007) states that 7 out of 21 surveyed EDs failed to deliver their service to an adequate quality level.

Focusing on the EDs of the Dublin area, the HSE identified that they operate at a utilisation level between 95 and 99 percent. The admission times to the attached hospital ward were longer than 6 hours for 57 percent of all patients and some (39 percent) waited longer than 12 hours. High utilisation and long waiting times are two of the three indicators for "overcrowding" – Sprivulis et al. (2006) addresses these in addition to diversion of ambulances as the main indicators of "overcrowding". The mortality rate due to overcrowding in EDs can be as high as 30 percent based on a study by Australian EDs (Richardson 2006, Sprivulis et al. 2006).

Improvement measures for the current situation have been introduced by the HSE especially for EDs:

> *"In October 2007, a maximum twelve-hour target was introduced by the HSE and in January 2009, a total waiting time target of 6 hours was set from the registration of the patient in the emergency department to admission or discharge."*(Buckley 2009, p. 10)

This target therefore aims to keep LoS times to not more than 6 hours and as a result – strictly speaking – no patient record should exceed this limit.

In addition to setting targets, a decision support tool is also applied by forecasting performance outcomes on the basis of statistical economical parameters. This tool provides a decision basis for planning. However, the outcome of this simulation approach is very broad and static as it cannot take into account the changes of the health status, perception or socio economic variations of a population (Behan et al. 2009).

Healthcare managers are obligated to find efficient solutions that can potentially reduce delay in order to reduce risks associated with overcrowding. To achieve this task, analytical techniques and approaches offered by operational research can be employed to investigate and improve processes (Hillier & Lieberman 2005). Eligible approaches would consider scheduling, resource allocation, capacity planning, and bottleneck analysis. Decisions in healthcare involve a high degree of uncertainty especially regarding patient demand. Simulation modelling can be used to facilitate / integrate the afore mentioned approach taking into account the level of uncertainty involved (Pidd 2004).

2.1.5 Background for Flexible Resource Allocation in Emergency Departments

Flexible workload management can be observed in high demanding working areas such as EDs where nurses and care personnel deal with several patients at a time. The benefits of this flexible scheduling strategy are:

- Flexible work allocation
- Spontaneous adjustment of work force to demand

Flexible workload management is a daily routine and very common in hospital environments. When a patient is receiving an x-ray for example, the nurse or porter is free to handle the next task or patient. At times when there is a high patient demand, this work arrangement can lead to stressful conditions whilst burnout symptoms are likely to occur. Burnout – a stress symptom – is a sense of frustration or failure and is common when there are insufficient personal and reduced vacation time (Sherman et al. 2006). It is also described as work-related emotional exhaustion, depersonalisation, and reduced personal accomplishment. Studies investigating the effect and cause of burnout symptoms among healthcare personnel have found a connection between burnout and spontaneous absenteeism (Diez-Pinol et al. 2008, Felton 1998, Hackett et al. 1989, Linzer et al. 2001, Shamian et al. 2003, Unruh et al. 2007). In Canada for example nurses showed the highest absenteeism rate among all employees in 1999 and created an economic loss of more than 16 million nursing hours due to injury and illness (Shamian et al. 2003). Unplanned absenteeism creates additional stress for remaining staff as the workload increases unless a substitute nurse is available. The substitute nurse usually works for several other units and may not be as experienced in that particular role as the nurse he / she is replacing. The need to maintain such an external staff pool adds further costs to the unit and lowers the quality of service. Investigations among senior nurses have shown that high patient load is related to increased restraint use and more patient deaths (Unruh et al. 2007). Another study in Australia has linked high patient demand with low healthcare quality indicators. It identifies an increase in patient mortality during observed periods of overcrowding within the emergency department (Richardson 2006).

A high mortality indicator is probably the worst imaginable drawback along with unadjusted staffing levels. Other unwanted side effects of unadjusted staffing levels are higher treatment error rates, sick pay due to absenteeism, or even compensation payment due to physical injuries. An increase of absenteeism levels implicates further negative effects on staff spirit and leads to higher administrational costs, additional workload, and stress (Honkonen et al. 2006). Thus, this additional stress could lead to further burnouts and perhaps even more absenteeism. In order to break this vicious circle it is important to identify the optimum utilisation level for staff so as they can operate in satisfactory conditions without consuming all resources. Therefore, managers responsible for creating a pleasant working environment for healthcare personnel must consider the aforementioned issues and work on improving conditions.

Resource scheduling is a domain which simulation modelling has excelled in handling due to its flexible approach which allows it to examine various strategies. Simulation optimisation has been successfully applied in many studies (e.g. Bard & Purnomo (2005), Centeno et al. (2003), Kim & Horowitz (2002), Rohleder & Klassen (2002), Wijewickrama & Takakuwa (2005), and Yeh & Lin (2007)). These studies focused on the shift arrangement in order to optimise the patient flow or treatment costs and also focused on finding the optimum utilisation of healthcare units considering patient waiting times. The latter domain is more difficult to investigate as it varies significantly from case to case. For example; a simulation model of an operating room identified that its optimum efficiency can be achieved between 85 to 90% (Tyler et al. 2003). However, this result cannot be generalised and can certainly not be transferred to other operating rooms or other units. EDs – demand driven units – on the other hand need more work to identify their optimum utilisation under all various constraints and limitations.

Simulation modellers have tried to achieve an accurate representation of healthcare units in general and emergency departments in particular. Due to the fact that these models of emergency departments tend to be larger and more complex, handling is more difficult than in the conventional factory world view (Hay et al. 2006). Considering the fact that the complexity of the factory world view should not be underestimated (Arisha & Young 2004), one might understand that developing an holistic model of healthcare units requires a great deal of effort. In order to offer a decision support model for managers, a generic model to consider flexible workload among nurses is developed and verified. This model explains the effects of overstaffing and understaffing in dependence of the arrival rate. Results identify a range of parameters where this system tends to become unstable with the consequence of long waiting times and / or high workload for staff. Unstable conditions are especially undesirable when a high quality suffers due to stressed staff and long waiting times (Thorwarth et al. 2009).

2.2 Complexity of Healthcare Simulations

Process simulation of flow systems as they are found in manufacturing, services, logistics and healthcare, involve many parameters. The first of these is the arrival time of each incoming item and service times for each workstation, which may differ for each processed item category. The aggregated service time for a product resembles the cycle time, throughput time, or LoS – depending on the field different descriptions are used to describe the same relationships. To gain a better understanding of a system, the parameters consist of input parameters (describing the arriving time and rate including the associated category of the item), internal parameters (service times, maintenance times, transport durations) and output parameters (cycle time, waiting times, output times).

The following sub chapter provides a brief overview of the complexity of simulation models with a focus on EDs. Formal descriptions, originating from manufacturing, are briefly discussed. In addition, certain limitations will be summarised which may mean that this approach of complexity consideration can only be applied to the healthcare sector. EDs have been chosen because they involve a high degree of dynamics and also often include a reserve pool of staff in case of high demand peak times.

2.2.1 General Complexity Considerations

Building models of a real system to be applied in simulations, requires an in-depth analysis of the system parameters. Not unlike mathematical or physical models, process flow models tend to involve a wide range of parameters. System analysis indicates the influence of the parameters on the behaviour of the system. In order to describe a system, there are two different possible fundamental approaches: the black-box model ignores the actual mechanism of a system while investigating relationships between input and output parameters. These relationships can be replicated by Neural Network models which can be trained to replicate the behaviour of the original system without a prior knowledge of the system – gaining insight into a black box is a difficult undertaking (Johannet et al. 2007, Setiono et al. 2000). A comprehensive guidance and framework with regards to this approach is given by Hagan et al. (2002). The second approach used to describe systems utilises reengineering methods – the aim is to identify the main mechanisms that trigger a certain behaviour of the system. There are two investigative methods which can be applied, either the observative method which uses quantitative statistical measures, or the experimental method which actively changes parameters of the actual system and measures the change of the output in accordance with the changing parameters. Changing parameters on a running system can be harmful or costly, especially when the outcome cannot be anticipated (Grover et al. 1995).

Modelling systems for simulation purposes are time consuming projects (Cooper et al. 2007, Davies & Davies 1995) and therefore complexity considerations are essential for the following aspects:

1. Estimate the creation time of a representative model;
2. Deliver a degree of appropriateness towards the expected outcome;
3. Data requirements;
4. Precision of results;
5. Simulation execution run time / processing time;
6. Maintenance;
7. Customer satisfaction;

8. Costs.

Arisha (2003) provides a comparison between complex and simple models in order to evaluate whether a complex model is in the interest of the customer, or if a simpler model would be more appropriate to deliver certain insights. The time consuming aspect of complex models should not be underestimated, because at the point when a model is ready to be used, the system under investigation may have already changed, thus making the results obtained from the simulation model obsolete (see Figure 2.2 (Pillai 1999)).

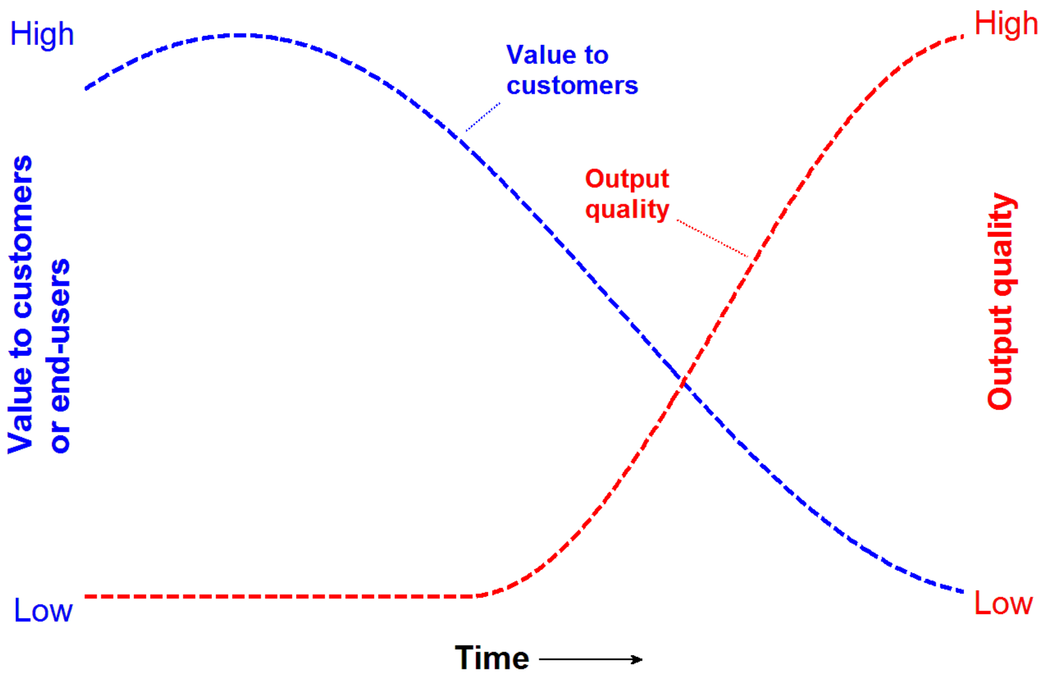


Figure 2.2: Development of the value gained from a simulation project over time. *Source: Pillai (1999).*

Complexity in Manufacturing

Within manufacturing systems, complexity has long been an issue under investigation. Generally it is distinguished among sequential, parallel and mixed allocation of machines / processes. Sequential allocation is described as Flow Shop, while a mixed combination of parallel and sequential routing of processes are commonly described as either Hybrid Flow Shops (Ruiz & Vázquez-Rodríguez 2010), in cases of parallel processing of sequential tasks, or Job Shops, where the routing of tasks is flexibly allocated (Pinedo 2008).

A common notation for Job Shops is provided by Graham et al. (1979) and is often cited as the (α, β, γ)-Notation where the production process, its restriction and their objective function are described respectively. Adams et al. (1988) provide a visual representation of the (α, β, γ)-Notation which is helpful with regards to solving scheduling problems. In a broader context, it is apparent that simulation is applied to scheduling problems in combination with optimisation in order to find the best scheduling arrangement of input items, which in turn allows a minimum cycle time.

Complexity Applied to Healthcare

Scheduling and planning with regards to patients in healthcare deserves a special consideration as patient arrivals may not always occur as arranged, and thus may disrupt the minimised LoS which has been forecast. In some areas of a hospital for example there are certain specialties where scheduling is applicable to a certain degree. The operating room for instance would be such an example because the patients arriving are known and the timetable can be arranged to a certain extent – while spontaneous changes due to acute cases or complications can also be catered for (Jebali et al. 2006). With the increase of variability – which occurs when a high number of acute casualty patients are involved – scheduling becomes more challenging (Tyler et al. 2003, Utley et al. 2003).

Planning Considerations in Healthcare

In order to evaluate and plan for the arrival of patients, healthcare managers tend to consult arrival patterns for their healthcare facility. Forecasting patient demand to an accurate level is greatly desired. As an arrival pattern, the Poisson distribution is commonly identified by investigating the hospital records. For example Bowers & Mould (2004) investigate the arrival pattern of an orthopaedic trauma centre which resulted in a stochastic pattern, where the Poisson distribution showed to produce the best fit. This distribution is varied in their means to adapt to arriving hour, day and season which is hence applied to the simulation model.

Another example of fitting distribution to arrival data can be obtained by de Bruin et al. (2007), where the frequencies – according to the grouped arrival minute category – display an exponential distribution, which is later shown to be Poisson. A very early study on hospital distribution approximation is that of Swartzman (1970), which is a publication on hospital distribution testing. Testing hospital records for statistical distributions is therefore a common exercise and can also be observed in the projects published by Patrick & Puterman (2007) and Cochran & Bharti (2006*b*).

However monumental the effort, patient arrival is not always clearly identifiable or approximations are difficult to retrieve. The DES models which require an arrival pattern are therefore striving for a close fit, which cannot always be guaranteed. A reasonable number of DES projects in healthcare can be identified, where statistical proof of a fit cannot be retraced in their publications and a Poisson distribution is assumed (Chu et al. 2003, Gutjahr & Rauner 2007, Utley et al. 2003, Vissers et al. 2007). The assumptions appear to be appropriate for the context of their research scope, as it takes time and effort to investigate the relevant patient arrival groups, which again leads to the cost and value evaluation.

2.2.2 Complexity Measure of Flow Models

Due to limited computing resources, complexity awareness and measurement is utilised to retrieve an estimation with regards to the proportion of computing resources which are consumed by a certain program or algorithm. Goldreich (2008) delivers a comprehensive theory guideline to calculate and estimate computational complexity. In a specific case, DES models can be seen as an instruction set (another expression for program or algorithm), which influence the item flow through the system. For overview purposes, these models are often represented as process flow models, which is an abstraction of the actual code. Process flow models provide an impression of the functionality and complexity which can be expected from a certain DES model. In 1976 complexity was as important if not more so, than it is today. This is due to the limited computing power and the limited redesigning of software during the construction phase. Therefore McCabe (1976) discusses a complexity metric based on graph theory (Berge 1976) and introduces the Cyclomatic metric which describes the behaviour of Work Flow (WF) nets. However, McCabe focuses on the behaviour of a program in an abstract WF-net, without regarding the actual code. In order to provide a measurement regarding the complexity of a graph, that is representing some code, the graph is structurally described by the number of edges, the number of vertices, and the strongly connected components. Thus delivering the reachability of the Cyclomatic metric as:

$$M = E - V + P \tag{2.1}$$

where E represents the number of edges, V the number of vertices and P the strongly connected components.

This metric can be applied to WF-nets which contain "IF THEN" constructs as well as to "LOOP"s constructs. Decisions and loops are commonly used within DES models, therefore the Cyclomatic metric is a valid representation of such models. Lassen & van der Aalst (2009) extend the Cyclomatic metric by considering the

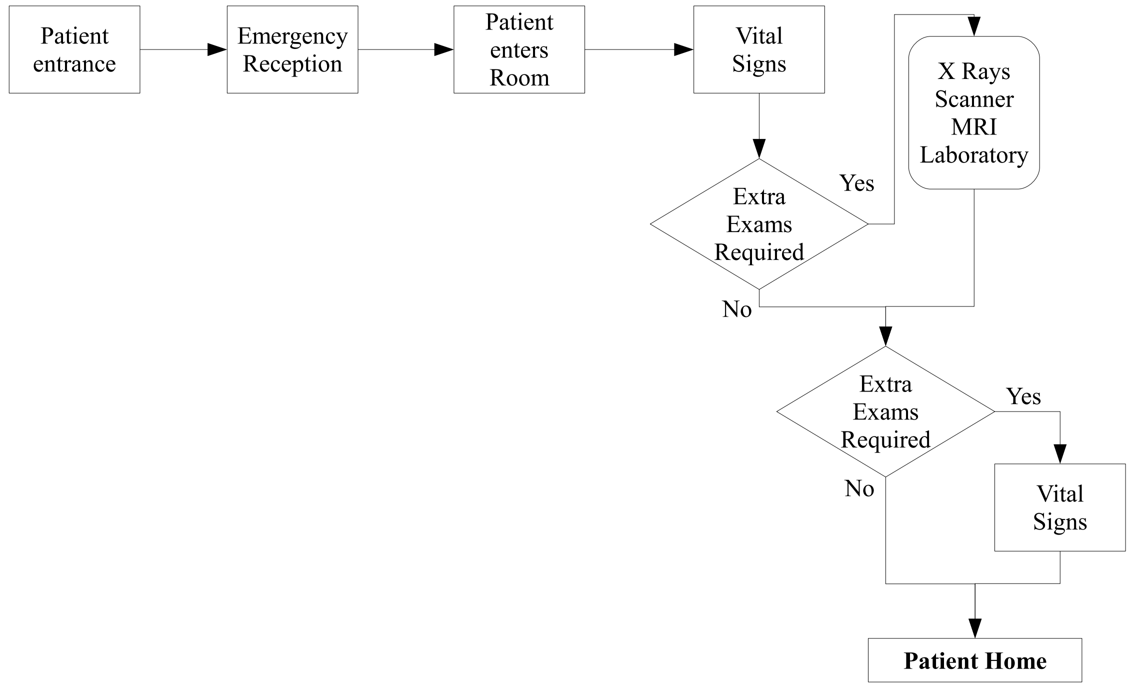


Figure 2.3: Patient flow for emergency patients.
Source: (Baesler et al. 2003).

absolute value of the edges and vertices:

$$ECyM = |E| - |V| + P \tag{2.2}$$

This Extended Cyclomatic Metric (ECyM) is one measurement which is used in order to describe the structure of a number of recent DES models that were used to represent ED with the use of DES. Table 2.1 summarises the displayed flow models presented by the corresponding author. For example, the process flow model provided by Baesler et al. (2003) shown in Figure 2.3 is calculated as:

$$ECyM = |E| - |V| + P = 11 - 8 + 6 = 9 \tag{2.3}$$

The reachability of this particular graph is 9 due to 11 edges, 8 vertices and 6 strongly connected components.

2.2.3 Complexity of Emergency Department Models

EDs are the departments which face the highest degree of uncertainty. The arrival of patients depends on the characteristics of the population inhabiting the catchment area. The primary mission of the ED is to provide acute care to patients. A common yet unique feature of EDs is their extensive use of prioritisation by allocating triage units, which are common and essential to providing immediate care for patients with the most acute conditions (Mackway-Jones et al. 2006). To guarantee a fast response to most of the acute patients, it is necessary to identify the upper limit of the utilisation of resources and staff of the ED in order to provide a reserved capacity for spontaneous increases in patient demand. An example of a generalised rule of thumb is a DES model detailing emergency admissions which is used to identify an inpatient bed occupancy level of less than 85% as the upper limit. This is done in order to avoid bed crises, which occur due to the lack of capacity reserve (Bagust et al. 1999). The effects of an occupancy level above 90% are dramatic. When this occurs, the hospital will regularly encounter scenarios which can best be described as bed crises. Consequently, a lack of capacity reserves endanger patients as the phenomenon "overcrowding" can occur. At this point it is important to note that the relationship between overcrowding and mortality rate shows that unreserved capacity may give reasons for concern (see Section 2.1.4 on page 34).

Publications on ED models illustrate the simulation model either in displayed flow charts or in written text. The assessed attributes of the DES models are summarised in Table 2.2. The first column shows the number of main sequential activities, whereas the shortest and the longest illustrates the shortest and longest possible path. Branches in the second column give the number of alternative routes through the system; the branches directly leading to the output are displayed in brackets. The activities within the branches are listed in the third column and grouped into the shortest and longest possible sub-route within a branch. Feedback loops and the total number of activities within the model are directly obtained in Table 2.2. The number of possible entrances and exits is given by the number of

Table 2.1: Extended Cyclomatic Metric of healthcare simulation models.

Author	Edges	Vertices	Strongly Connected Components	ECyM
Komashie & Ali (2005)	8	9	3	2
Hoot et al. (2008)	6	6	4	4
Yeh & Lin (2007)	9	8	4	5
Blake & Carter (1996)	6	5	4	5
Mayhew & Smith (2008)	7	5	3	5
Mahapatra et al. (2003)	9	4	4	9
Fletcher et al. (2006)	11	9	7	9
Baesler et al. (2003)	11	8	6	9
Bowers et al. (2009)	20	18	7	9
Centeno et al. (2003)	11	7	6	10
Ruohonen et al. (2006)	13	9	7	11
de Bruin et al. (2007)	12	3	3	12
Miller et al. (2004)	17	10	5	12
Ashton et al. (2005)	13	3	2	12
Takakuwa & Shiozaki (2004)	18	11	6	13
Gonzalez et al. (1997)	16	8	7	15
Martinez-Garcia & Mendez-Olague (2005)	25	13	5	17
Kuban Altinel & Ulaş (1996)	23	12	8	19
Sinreich & Marmor (2005*b*)	36	27	15	24
Blasak et al. (2003)	43	24	12	31
Wiinamaki & Dronzek (2003)	60	16	9	53
Samaha et al. (2003)	57	12	38	83
Model of this field study	168	43	15	140

inputs and outputs respectively.

In order to provide an alternative measure with which the complexity of a DES model can also be compared, the following estimated measurement is proposed and displayed in the ninth column, which is entitled complexity estimated measure. This measure is obtained by subtracting the number of branches that are directly linked to the output from the total number of branches that can be found in a model. These branches do not contribute considerably to the complexity, as subsequent decisions are not made at this stage. The resulting number is hence multiplied with the number of total activities counted. This will then provide the estimation, which means that the models can be compared with regards to their degree of complexity. This Estimated Degree of Complexity (EDC) can be described by:

$$EDC = (E - E_a) * P_a \tag{2.4}$$

where E are the edges (branches), E_a the number of branches directed to the output and the P_a represents all components. This method is not applicable to all the models as not all required information can be retrieved from the publications. In this case a close look at the set up of the model is inevitable and certain characteristics of the model must be evaluated directly.

When comparing the results of the alternative complexity estimation EDC with the ECyM, a difference for certain models is apparent, however the trend of the complexity is similar. For example, the authors are ranked according to their degree of complexity in Table 2.1 and Table 2.2. Only few authors differ in their ranks. Bowers et al. (2009) for instance, is ranked the 17th most complex model according to ECyM while it is 5th according to EDC.

The investigated models vary in their complexity: most of the investigated models consider less than ten activities (Ashton et al. 2005, Baesler et al. 2003, Connelly & Bair 2004, de Bruin et al. 2007, Fletcher et al. 2006, Hoot et al. 2008, Komashie &

Ali 2005, Kuban Altinel & Ulaş 1996, Miller et al. 2004, Ruohonen et al. 2006, Yeh & Lin 2007), while only five consider 10 to 20 activities (Centeno et al. 2003, Gonzalez et al. 1997, Mahapatra et al. 2003, Martinez-Garcia & Mendez-Olague 2005, Takakuwa & Shiozaki 2004). Additionally, four models consider more than 20 activities (Blasak et al. 2003, Samaha et al. 2003, Sinreich & Marmor 2005*b*, Wiinamaki & Dronzek 2003). The highest number of activities is considered by Samaha et al. (2003) which illustrated a model with 52 activities. Blasak et al. (2003) displays 90 activities of which a third directly describe the patients' journey through the ED. The last row of Table 2.2 displays the current properties of the DES model of the St. Vincent University Hospitals' ED. Focusing on the estimated complexity measure, it can clearly be seen that this model has a relatively high degree of complexity in comparison to the other models, which is supported by the objective ECyM metric (Table 2.1).

Modelling the complex behaviour of an ED is a challenging task due to the interaction of human and physical resources. Medical staff, for example, are rarely dedicated to one patient or task, they treat several others while waiting for other processes. This diversity of process interaction can be described as multitasking, a common feature of ED operations. Yet, multitasking is rarely considered in DES models of EDs (Günal & Pidd 2006). Several tasks and processes, depending on certain resources, result in interrupt-driven system behaviour demanding a well adjusted allocation of human and physical resources (Wild et al. 2004). The impact of multitasking on ED simulation models certainly warrants further investigation, especially on the background of scarce shared resources.

2.2.4 Barriers due to Complexity

However ideal the methodology appears, previous models on healthcare facilities tend to be an abstract reflection of the original processes (compare Table 2.1 and Table 2.2 on pages 47 and 50 respectively, in this section). Maintaining a low detail

Table 2.2: Description of simulation models applied in EDs.

Author	Main seq. Activities (shortest/ /longest)	Branches (directed to output)	Activities in Branch (shortest/ /longest)	Number of Feedback-loops	Total Activities
Blake & Carter (1996)	-	3 FORTRAN Subroutines	-	-	500 lines of code in SIMAN
Bagust et al. (1999)	-	-	-	-	-
Rossetti et al. (1999)	-	-	-	-	-
Hoot et al. (2008)	6/6	2(2)	1/1	0	6
Miller et al. (2004)	5/5	1(1)	1/1	0	5
Takakuwa & Shiozaki (2004)	3/7	5(5)	1/3	0	12
Connelly & Bair (2004)	-	-	-	-	7
Komashie & Ali (2005)	-	-	-	-	6
Ashton et al. (2005)	3/3	10(11)	0	0	6
de Bruin et al. (2007)	3/3	7(5)	0	1	3
Baesler et al. (2003)	7/9	2(1)	1/1	0	9
Ruohonen et al. (2006)	4/8	2(0)	1/1	1	8
Yeh & Lin (2007)	6/7	2	1/1	0	8

Continued on page 52 ...

Continued on page 51 ...

(...Table 2.2 continued): Description of simulation models applied in EDs.

... continued from page 50

Author	Input / Output	Data	Comments	ECyM	Estimated Degree of Complexity (EDC)
Blake & Carter (1996)	-	3 days	-	5	
Bagust et al. (1999)	-	-	Spreadsheat model	-	-
Rossetti et al. (1999)	-	-	Few Descriptions only	-	-
Hoot et al. (2008)	1/3	57,995 patients	-	4	-
Miller et al. (2004)	1/2	Assumptions	-	12	-
Takakuwa & Shiozaki (2004)	2/3	-	-	13	-
Connelly & Bair (2004)	-	682 patients	12,714 modules	-	-
Komashie & Ali (2005)	1/2	6,000 patients	-	2	-
Ashton et al. (2005)	1/11	850 patients	Simplified	12	0
de Bruin et al. (2007)	2/5	2,838 patients	-	12	6
Baesler et al. (2003)	1/1	-	-	9	9
Ruohonen et al. (2006)	1/1	4,000 patients	-	11	16
Yeh & Lin (2007)	1/1	7 months	-	5	

Continued on page 53 ...

(...Table 2.2 continued): Description of simulation models applied in EDs.

... continued from page 50

Author	Main seq. Activities (shortest/ /longest)	Branches (directed to output)	Activities in Branch (shortest/ /longest)	Number of Feedback-loops	Total Activities
Centeno et al. (2003)	8/12	3(1)	1/3	0	12
Gonzalez et al. (1997)	6/12	4(2)	1/5	0	13
Martinez-Garcia & Mendez-Olague (2005)	7/9	7(5)	9/9	0	16
Mahapatra et al. (2003)	7/10	5(1)	1/2	0	15
Bowers et al. (2009)	8/12	11(1)	1/2	0	13
Kuban Altinel & Ulaş (1996)	9/18	26(2)	4/8	0	8
Samaha et al. (2003)	13/31	11(0)	2/4	1	52
Blasak et al. (2003)	16/(33+ 18+27)	21(0)	1/7	2	35+ (19+36)
Wiinamaki & Dronzek (2003)	8/16	15(0)	1/12	0	41
Sinreich & Marmor (2005*b*)	12/22	19(1)	1/10	3-4	35
Model of this field study	9/22	64(0)	7/13	0	57
Fletcher et al. (2006)	5/8	2(0)	2/3	0	8
Mayhew & Smith (2008)	2/3	4(1)	2/3	0	5

End of Table 2.2

Continued on page 53 ...

(...Table 2.2 continued): Description of simulation models applied in EDs.

... continued from page 51

... continued from page 52

Author	Input / Output	Data	Comments	ECyM	Estimated Degree of Complexity (EDC)
Centeno et al. (2003)	3/1	-	ILP programing	10	24
Gonzalez et al. (1997)	1/2	-	-	15	26
Martinez-Garcia & Mendez-Olague (2005)	1/5	3 months	-	17	32
Mahapatra et al. (2003)	1/1	160,000 patients	-	9	60
Bowers et al. (2009)	2/3	-	-	9	60
Kuban Altinel & Ulaş (1996)	1/3	14,000 patients	-	19	192
Samaha et al. (2003)	2/2	-	-	83	572
Blasak et al. (2003)	1/5	-	-	31	595
Wiinamaki & Dronzek (2003)	1/7	-	-	53	615
Sinreich & Marmor (2005*b*)	1/1	16,250 patients from 5 hospitals	models patient arrival data	24	630
Model of this field study	2/5	79,641 patients	30,000 modules	140	7552
Fletcher et al. (2006)	1/1	-	-	9	16
Mayhew & Smith (2008)	1/3	May-July 2002	-	5	18

End of Table 2.2

level has the advantage that the development time of such a system is kept short due to computational, debugging and complexity issues. The modeller is caught or tethered up by unnecessary details, however, important dependencies may be lost or simply overseen, which could lead to the recommendations, made on the abstract model, not delivering the anticipated results. With regard to this effect it is often said that simulation is a shadow of reality. To overcome this conception, a valid solution would be to increase the detail level of the simulation model, which again risks the confrontation of the aforementioned disadvantages.

In computational complexity theory, complexity is well defined by the number of runs that a deterministic or non-deterministic algorithm or function must go through. A function is abstracted by its consumption of resources (e.g. number of loops, recursive function calls, etc...) and describes the use of the computational resources that can be used to estimate the computational efficiency of an algorithm (Goldreich 2008). In DES, complexity is often considered by the number of utilised functions (such as queues, activities, merging elements, etc.), diversions within the routing, and by the number of processed items. Hence it can be said that the size of the model determines the grade of complexity, which in comparison to the computational complexity theory, is a rather crude measure. Having said that, it does give an idea of the computational resources that are required for the execution of simulation models.

However high the desire of the modeller may have been to add complexity in structure and size, there is a certain reluctance from the modeller to apply measures which increase the complexity of the model. Introducing complexity thus faces barriers due to several factors:

- Higher amount of pre-processed data (e.g. statistical processed process data);
- More potential error which results in a high debugging effort;
- Delivery of the model takes longer (critical for a quick changing environment);
- Difficult to maintain the overview which requires more documentation effort;

- Adaptations are difficult or difficult to address, which means that the model appears difficult to adjust;
- Generalisability or transferability of the results is difficult.

Due to these resentments, experts in simulation modelling recommend starting up with simple models and then evaluating whether complexity is really required (Banks & Autosimulations, Inc. 2000, Banks et al. 2005, Law & Kelton 2000, Sackett et al. 2007).

Starting up simple is not necessarily sound advice, especially as integrated networks are already complex in nature. The focus on a subset of the entity does not deliver the whole picture and fails to deliver results on how the simulated system behaves in relation to other systems. One might argue that system dynamics (SD) may be an appropriate solution for simulating an integrated network, however on the other hand, the details, which cause certain effects, are not considered, or are not easily addressed or identified. For example, within a SD network, blockages due to over-utilisation of a specific resource of the subsystem cannot be identified when the overall system is investigated. Therefore, expanding the scale of DES may be an appropriate approach. This example demonstrates that a structured approach like FRA is essential to aid the DES modeller in building better complex models.

The last two examples extracted from Table 2.2 are examples of the two extremes among the comprehensive level of ED simulation models. Building models like EDSIM is time consuming but has the advantage of a high degree of trust from decision makers. In order to ease the burden of such large models, specific modules and libraries are required and help the modeller to accelerate the building process. As elaborated above (in Section 2.3.5 on page 80) for reusability purposes a guideline must be provided in the libraries and modules in order to equip the modeller with the appropriate knowledge and tools for the process.

2.3 Simulation Applications in Healthcare

A comprehensive and regularly cited review is given by Jun et al. (1999), who reference 117 articles which were published between 1952 and 1997. This paper refers to previous research on single or multi-facility healthcare clinics and summarises articles written on different topics such as patient flow and allocation of resources. In addition, it also provides an outlook on future directions. Preater (2002) focuses on queues in healthcare with a grouped bibliography (Preater 2001) such as appointments, outpatients and waiting lists, departments, compartmental modelling, ambulances, and miscellaneous. Another focused review is given by Cayirli & Veral (2003). Their review concentrates on outpatient scheduling in healthcare and divides the topic into its elements and methodologies. Here simulation is mentioned only as a side topic and not as a viable solution technique. A focused overview on the planning and scheduling of an operating room is provided by Cardoen et al. (2010), where simulation applications are grouped into comprehensive categories that resemble topics of operational research interests.

Hence, a systematic and focused review is given by Fone et al. (2003) which describes a survey of articles on the use and value of computer simulation modelling applied in healthcare. This survey uses data resulting from the automated queries on certain keywords of 60 articles in various literature databases. Another survey and discussion paper has been published by Eldabi et al. (2007) in which the authors conclude that simulation, with its flexibility, has advanced to a single solution-based method to solve problems in healthcare. Limitations and boundaries of the term simulation can be found in Streufert et al. (2001), which offers a good overview of simulation projects applied in healthcare. Various references for simulation projects on large scale emergencies are cited by Hongzhong et al. (2007), who also present a modelling approach to provide communities with emergency care in a catastrophic event.

2.3.1 Requirements of a Decision Support System

A Decision Support System (DSS) is an assistance tool with many characteristics. In the healthcare context, there are two types of DSS. Firstly is a DSS which supports decisions made by medical staff with regards to treatment. This type will be referred to as a Clinical DSS (CDSS). In addition there are also Performance DSSs (PDSSs) which are utilised in order to monitor or improve the overall performance of a healthcare facility. Officially, there is no official differentiation among PDSSs and CDSSs, therefore many simulation based DSSs which are primarily designed to increase the performance of a healthcare facility are labelled as CDSSs.

Medical DSSs are designed to give advice to medical staff in uncertain cases. Generally this advice is backed up by statistical information regarding treatment success / failure of medical reports and studies. The "Golden Standard" for treating diverse diseases or illnesses defines actions in cases of certain developments and focuses primarily on the medication of a patient (ELSEVIER 2011, Osheroff et al. 2005). Clinical Pathways (CP) however, provide a more detailed insight into the treatment process and provide a guideline, which is constantly assessed (Hall et al. 2006). CP thus increase the transparency for decision making.

DSSs aiming to increase the performance of a healthcare facility do not usually function as a CDSS in medical context. The PDSSs aim to increase the usage of limited capacity within a facility (Groothuis et al. 2001) or aim to optimise the performance output via scheduling measures (Everett 2002). The routing of the patient is also under consideration while accessing a PDSS, either while designing a healthcare facility (Vos et al. 2007) or redesigning the patient flow through the system via implementing "fast tracks" (Rossetti et al. 1999, Cooke et al. 2002, Sinreich & Marmor 2005*a*). PDSSs therefore aim to support the management in their decisions and do not usually interfere with the decisions of the medical staff.

With the increase of the application of HIS, the usage of computers during consultation as a supportive tool is increasing whilst the paper based patient file is gradually becoming obsolete. In addition to the patient data, the HIS may integrate a CDSS which aid medical staff in their decision making. A study investigates the degree to which GPs are managing their workload with computer aided decision making. This study concludes that the full potential of the system is not utilised due to a lack of knowledge regarding its workings (Gibson et al. 2005).

PDSSs are often simulation based as simulation projects applied in healthcare are becoming increasingly popular. This can be derived from the fast growing number of publications applied in this field. Figure 2.4 shows how the publication rate has increased throughout the last 15 years. This figure is obtained by accessing the Publish or Perish database and by applying the search as follows: the black bars display the total number of possible DES projects applied in healthcare (Harzing 2009). This number is obtained by entering the following keywords: "discrete event simulation" and either of the following: "patient", "healthcare", "hospital", and "emergency department". The white bars display the number of DES projects applied in EDs, the search has been done respectively according to the terms: "discrete event simulations" and "emergency department". This is certainly not an accurate representation of the amount of research done in this field, but gives a good description of how the interest of healthcare has increased in applying DESs.

Purpose and objective of the need for a simulation project specifies the range of the detail level that is set by the initiator and applicant in agreement with the modeller. There are several potential users at different management hierarchy levels and its improvement objectives differ throughout the hierarchy. For example: the objective of operational management is interested in finding the optimum setting of staff and supply on either a day to day basis or on a monthly basis, whereas cooperative management requires information for a longer time span which can help to plan new treatment centres, or to plan the allocation of resources on long term contracts. The operational and cooperative management are those which apply

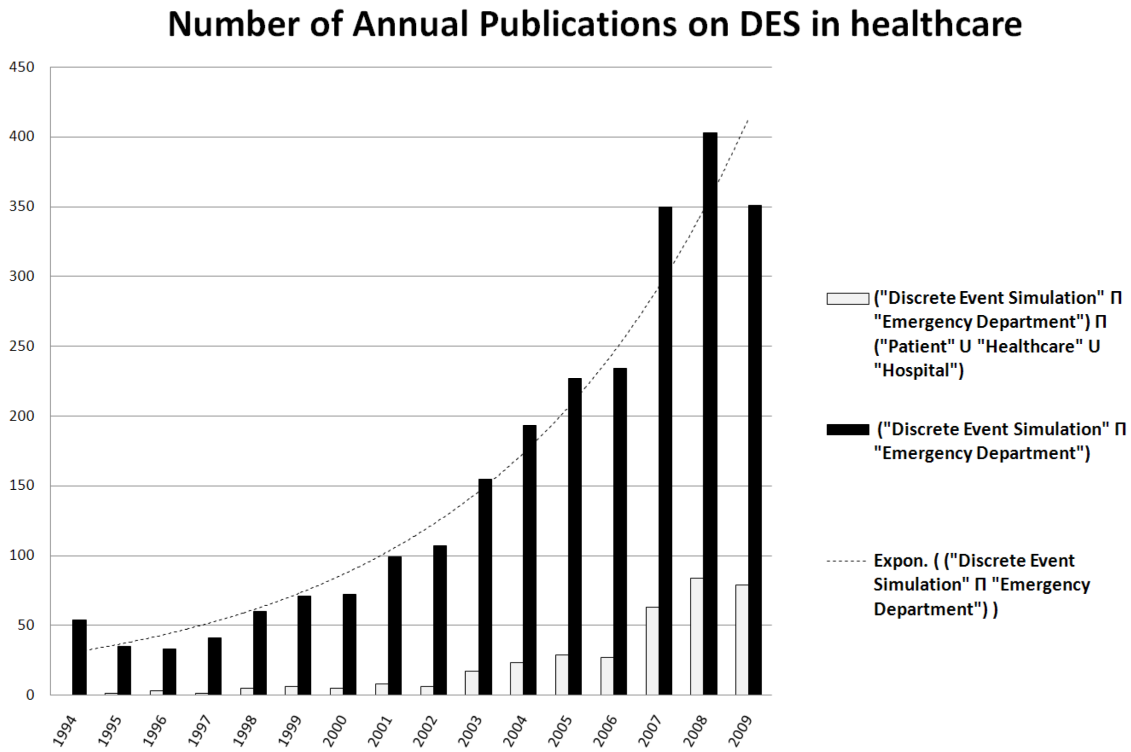


Figure 2.4: Number of annual publications on simulation applied in healthcare. *Source: (Harzing 2009).*

DESs in order to retrieve the information that supports their decision making. By increasing the time span, especially for strategic management, different modelling techniques such as process flow simulation or heuristic simulation are more suitable (Vissers & Beech 2005). Figure 2.5 groups different stakeholders according to their objective timespan and their operational function. Whichever technique is required, with the development and improvement of HIS, the information is available to build appropriate models which fulfil the needs of the decision makers.

As maintaining or increasing the quality of service is an ongoing task for healthcare decision makers, they strive for new techniques which could yield potential solutions in the future. With increasing costs comes the demand for changes and improvements. With this in mind, one feature of process simulation catches the attention of healthcare decision makers: *Scenario Testing:* scenarios can be tested on a model which represents the healthcare facility without interfering with the real system. In order to build a representative model it is essential to retrieve all neces-

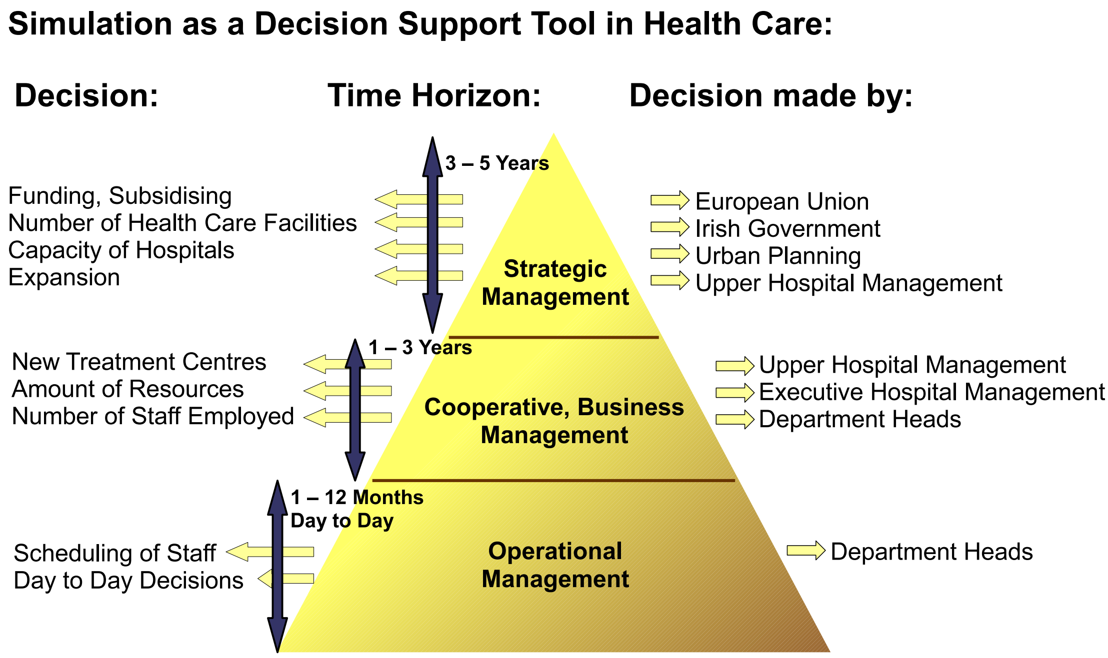


Figure 2.5: Simulation as a Decision Support Tool in healthcare associated with management level according to time span and decision purpose.

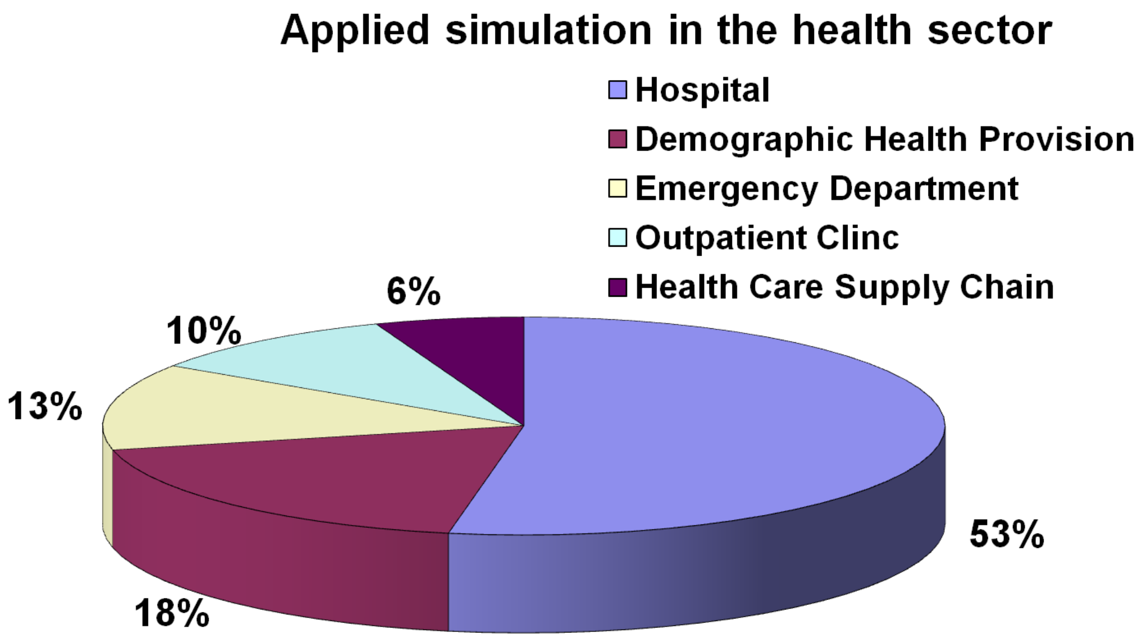


Figure 2.6: Distribution of applied simulation in different health sectors.

sary information regarding the system under investigation. Data mining techniques provide a wide variety of ways in which to use quantitative and qualitative data (Berry & Linoff 1997, Bradley et al. 1999, Ceglowski et al. 2007, Sundaramoorthi et al. 2006). Hospital and patient records become an invaluable source of information, as well as staff interviews, which provide an overview of how the patient flows through the facility. Combining this data in a conceptual model, delivers a first source for discussion regarding the validity of the modellers idea of the system.

Once the conceptual model is translated into an executable simulation model, "what-if"- questions can be answered by creating test scenarios. The consequence of the scenarios can be investigated and potential avoidance strategies can be implemented. Further investigations regarding the model identify bottlenecks – allowing increasing throughput on a certain section, the objective being to increase the flow of items. KPI measurements allow for a comparison of the as-is state with the to-be state of the model. The combination of "what-if"- questions, optimisation, the modelling itself, bottleneck identification and KPI comparison enhances process simulation and make it a very attractive solution method for the healthcare domain due to its manifold analysis possibilities.

2.3.2 Simulation in General

Simulation has successfully been applied in manufacturing as well as military and logistic sectors and has proven to have many advantages such as (Pegden et al. 1995):

- Scenario testing without interference with the real system;
- Bottleneck analysis;
- Capacity planning;
- Investigations of certain phenomena;
- Investigation of correlations of variables;

- Integration of optimisation.

To access these advantages, many simulation packages are developed, which allow the user to adjust simulation models to the analysed system. A survey, which until recently appeared every two years, lists 48 different products, which allows a comparison of their main features (Swain 2003). Several of these packages originate from SLAM (Simulation Language for Alternative Modelling) and offer a shell to build sophisticated models of the analysing system. These packages differ in certain key features (Banks et al. 2005):

- Model building;
- Runtime environment;
- Animation and Layout features;
- Output features;
- Definition of variables, functions and subroutines;
- Vendor support and product documentation.

Increasing performance is one domain of operations research and its application in healthcare is increasing. Simulation, which is one topic among a wide field of operation research, is acquiring a greater acceptance as a solution finding methodology among hospital managers. Almost 30% of simulation projects were implemented between 1995 and 2008 (Thorwarth & Arisha 2008), which is a significant rise when compared to the figure of 8% identified in 1980 (Wilson 1981, p. 825). The potential of simulation to achieve an increase in performance within the available resources is one of its major benefits. In addition, its flexibility to integrate other solution techniques, such as optimisation, artificial intelligence, and data mining, as well as its capability to consider uncertainty and complexity, enhance the reputation of simulation as a solution finding technique within healthcare.

In general, simulation describes the procedure of finding a replica of an object or system which allows the application of tests or scenarios without harming or interfering with the original object. Process simulation differentiates between continuous flow and DES with the latter being the main focus of this research. An often cited definition which defines DES is provided by Balci (1988) where four modelling structure methods are identified:

- Process-interaction method;
- Event scheduling method;
- Activity scanning method;
- Three-phase method.

These four methods describe a system in different detailed abstraction degrees: the highest detail level can be obtained by the process interaction method which simulates each state and event. Within this method, for example, ”waiting” is considered as a process. The next higher degree in abstraction level is the event scheduling method, where time advances to the moment when something happens next – ”waiting” considered here as in a queue and as a rather abstract process in comparison to the process-interaction method. The next abstract modelling structure is the activity scanning method, which is also known as the two-phase approach. Within this research the simulation software is composed of two independent modules which scan a certain amount of time in the first phase, and in the second phase the system is updated according to the scanned events. The three-phase method is an equally abstract modelling structuring method to the two-phase method. The scanning and update processes are divided into three separate steps: first, time is advanced to the next event. The second phase releases all resources involved in the activities, and the last phase starts activities in accordance with the global picture and the available resources. Within this research, the applied field research is modelled in a simulation software package which uses the event scheduling method.

Simulation is a very flexible tool and can be applied in various domains and environments. We can distinguish between object simulation, such as flight simulator (which shall not be of interest here) and process simulation, which is the primary use of industry and servicescape. Process simulation is a collective term for continuous flow simulation, process flow simulation and Discrete Event Simulation which makes use of models to reflect the behaviour of real systems. Continuous simulation is often applied to control processes in electrical engineering whereas process flow simulation is commonly used to describe production lanes, where a large number of objects flow through the system (Law & Kelton 2000). DES is characterised by its ability to capture and describe activities that affect the system and items. The type of simulation used is determined by the objective, required detail level, and the domain characteristics. Systems where several million objects pass through would more likely benefit from being modelled as a process flow simulation, whereas a system which has a determinable amount of objects, profits from the use of discrete event simulation. This is due to the fact that here, the detail level can be increased to any activity in order to investigate the effects and causes of their interaction with any other item or activity within the system.

In comparison to manufacturing, where raw material is transformed by interaction of manpower and/or machinery into finished products, patients are served on the basis of their diagnosis which must be identified in advance. In certain healthcare facilities, diagnosis is a major contribution within the patient care process, such as emergency departments, outpatient clinics, and partly hospitals. The other fraction of hospitals plan their operating theatre timetables on the basis of diagnoses which have been identified in advance. Since 1983 DRGs have been used in order to categorise the complaints of patients and to facilitate a higher transparency of founding in healthcare. In 1998 there were 495 DRGs identified with several thousand ICD-9 codes – International Classification of Diseases (ICD) – which indicates side diagnoses (McGuire 1998). The ICD-10 is the latest standard, which is assessed and supervised by the World Health Organization (WHO) (World Health Organization

(WHO) 2010). The DRGs were an important step towards the establishments of patient care pathways. While DRGs are setting an economic target for the healthcare facilities, the care patient pathways enable a process optimisation of the patient flow. Considering the high amount of DRGs, the amount of variations is high and the description of care patient pathways is therefore complex.

Furthermore, boundary features of healthcare to manufacturing are similar to those that are common in the service sector. For example, the system structure and its components are not laid out in detail or even hard to obtain and special attention is necessary for their identification. Another difference of manufacturing is that manufacturing uses throughput time as a KPI, whereas in healthcare the throughput time is replaced with the patient LoS and an additional KPI focuses on the patient waiting time, which is commonly used to set targets for healthcare facilities. Examples of this include the four hour target in the NHS (Department of Health (DoH) 2001, Proudlove et al. 2007) or the six hour target set by the HSE in Ireland (Buckley 2009). The service time and / or treatment time is heavily dependent on the cooperation of the patient. Complications for example can occur and afflict a sudden alternation to the anticipated journey of the patient through the healthcare facility. With regards to simulation modelling, the focus is often on how to achieve more with the available resources, which is more often than not the initial starting point for the analysis of the healthcare system under investigation. Recapitulating these features, it is increasingly obvious, that whilst manufacturing is very complex, it shows weakness when compared to healthcare. Indeed healthcare puts a high degree of variability and uncertainty to its systems, which is a special challenge for the simulation modeller (Laughery et al. 1998).

For decision makers there are several good reasons to apply DES as an analysis tool. These advantages are described by many authors (Banks et al. 2005, Law & Kelton 2000, Pidd 2004) and can be summarised as the following:

1. *Sound decision making* – Investments and changes to the system can be evalu-

ated and the potential benefit or loss is forecast on a sound decision basis. The opportunity to ask "What-If" questions is one of the most common procedures within a simulation analysis (See Dooley 2002);

2. *Thorough investigation of events* – On any particular point of interest, simulation allows the investigation of events by compressing or decompressing the time line. Repetitions of a single event allow statement about their degree of randomness or their systematic occurrence (See Ceglowski et al. 2007);

3. *Understanding of cause and effect* – Are events dependent on or independent of each other? Is a bottleneck in a certain area a cause for a shortage somewhere else? These questions are easily facilitated and answered (See Robinson 2007*b*);

4. *Scenario analysis* – Alternatives, opportunities or even new possibilities can be investigated without interfering with the actual system. The analysis of scenarios allows an improvement of the system (See Arisha et al. 2004, Swisher et al. 2001);

5. *Investigation of problems* – Complex systems such as a modern factory floor involve a high number of variables. It is therefore difficult to consider all the variables in any given moment. Simulation, however, allows a focus on certain effects by providing control of inflicting variables. The effects become more transparent and avoidance strategies can be considered (See Stahl et al. 2004);

6. *Identification of bottlenecks* – Investigations on the flow of the items explain shortages or unwanted queues. Hence an increase in the capacity of the certain shortage can now resolve the bottleneck (See Gonsalves & Itoh 2009);

7. *Understanding limitations* – Eliminating one bottleneck on one side creates a new bottleneck in a different location. Bottlenecks are common for complex systems, and it is impossible to eliminate them all. The only possibility, is to identify a trade off, which represents the most optimum setting for the system (See Hall & Connelly 2006, Kuljis et al. 2001);

8. *Transparency* – Understanding of the system is increased due to the required analysis phase on the system under investigation. Many simulation studies had already achieved valuable insight, long before the first simulation run (See Robinson 2007*b*);

9. *Guided implementation of change* – Once a scenario has been established, which describes the future "to-be" - state, simulation can guide by its implementation. Tests and descriptions on intermediate scenarios on the model can provide invaluable information in order to establish a smooth and uninterrupted change (See Pidd 1999);

10. *Visualisation* – With the use of animation a new perspective to the setting is offered which allows additional analysis opportunities. Thus hidden bottlenecks become transparent, unnecessary idle times appear obvious, and redundant routes are visible (See Rohleder et al. 2007);

11. *Educational purposes* – Simulation can be used to familiarise staff with the system and the interacting processes. New insight offers a sound understanding of the interfaces to other sectors and hence increases the commitment of staff (See Connelly & Bair 2004, Streufert et al. 2001, Andersson & Värbrand 2007);

12. *Identifying requirements* – Resource utilisation and its consumption can be calculated on the actual utilisation of resources. These calculations are often based on estimations which only reflect an average over whole consumption, whereas simulation offers the opportunity to take peak utilisation into account, which often results in a higher write off rate (See Thorwarth et al. 2009, Ivaldi et al. 2003).

Despite these many advantages, DES also has its limitations:

1. *Special training required* – Building simulation models requires special training in two aspects. First the modeller must obtain a sound understanding of the system, and secondly he / she must be familiar with the procedure and process of building a representative system. Despite many advances in the provision

of simulation modelling packages which smooth out the journey of modelling, the modeller still requires expertise in these two areas (See Lowery 1996);

2. *Experience required interpreting simulation results* – Not only must the modeller have a sound experience, the person interpreting the results must also be knowledgeable with regards to the model itself, so that he / she is capable of understanding the difference between random events and systematic appearances. A thorough understanding of statistics is also essential (See Robinson 2007*b*);

3. *Time consuming procedure* – Modelling is just one part of the overall simulation project. This project consists of data analysis, conceptual modelling, communication with stakeholders, modelling itself, verification and validation, optimisation or scenario analysis, and also the implementation of all essential steps in the simulation project. For example, the better the data retrieval and analysis is, the better set up the decision basis for the model. A short cut taken here will inherit itself through the whole model and will most probably endanger the trustworthiness of the entire project (See Lowery et al. 1994);

4. *Transferability / reusability* – Modularity principally allows building model components that are easy reusable. However, as was highlighted earlier (Section 3.3), the reusability of models in healthcare is apparently very rare. Recommendations for building such frameworks are available and theories have already been discussed, but the basic element, a common module library, is still not available (See Günal & Pidd 2010).

Considering the outstanding features of healthcare, such as variability and uncertainty, one might agree with the common misconception, that healthcare is not suitable for process simulation as it is applied in manufacturing. For that reason many researchers and simulation modellers see healthcare as a special challenge, and offer many solutions to model healthcare facilities.

2.3.3 The Healthcare Domain

To help decision makers in healthcare facilities, simulation has achieved a significant level of acceptance among clinicians and hospital managers (Jacobson et al. 2006). Despite the fact that it was first applied in 1952 with the development of a queuing system for hospitals (Bailey 1952), the distribution of DES is less prevalent in healthcare than in other sectors (Sanchez et al. 2000). However, the last decade has witnessed a major change: the publication rate of simulation applications in healthcare has been doubled compared to the previous three decades (see Figure 1.1 on page 15).

Healthcare in general is charged with providing care and / or treatment for the benefit of an individual patient or of a population. Simulation concerning the benefit of a population is often realised by another type of simulation which is system dynamics. But as soon as the focus is set on modelling a certain facility, DES is the preferred methodology. Reviewing the literature on simulation models in healthcare facilities, it can be seen that approximately 78% of projects and studies have utilised DES. Many use DES in conjunction with other solution finding techniques, such as optimisation techniques, like genetic algorithms, linear programming, and so forth. Process simulation is often described as a flexible approach, which allows integrating and combining many variances of solution finding techniques, either embedded within the simulation model or closely interacting with the simulation model. This flexibility facilitates process simulation to an ideal solution finding technique.

DES has proven itself as a flexible and adjustable solution technique for a wide range of domains. Increasing the transparency of a complex system, through ongoing investigation, is one of the important positive side effects, which results from a simulation project of a facility. Simulation also encourages the creativity of the user in that he / she might not only state "what-if "-questions within a simulation model, but also be tempted to ask the "what-if I could model the whole system"-question. Very soon, the simulation approach (Banks et al. 2005) as we know and apply it today will face the barrier of complexity. This may however be achieved by decreasing the detailed level to which the model represents the actual system. Complexity of a system is a constraint for DES due to computational power and limited lifespan of manpower, which in this case is the modeller.

However, to overcome the barrier of complexity, models have been built which consider the differing detail levels of certain healthcare facilities, such as those which investigate certain patient groups like the cardiac in-patients (de Bruin et al. 2007) or those which focus on an entire facility within a hospital like an Intensive Care Unit (ICU) (Ridge et al. 1998). There are also models which take into consideration an entire hospitals (Harper & Shahani 2002) or even a network of hospitals (Chu & Chu 2000). The detail level is dependent on the size of the model – not all information is necessarily relevant for a sufficiently representative simulation model. Obtaining the certain detail level at which a facility is optimally represented is an ongoing discussion in the academia (Young et al. 2009).

Large scale simulation models may become quite unmanageable. This was the conclusion reached by Moreno et al. (1999) after studying an entire hospital complex located in De la Candelaria, Tenerife. A divide and conquer design methodology is used in order to develop a micro and macro model of the hospital on a patient flow basis. With this approach the target is to identify and eliminate bottlenecks. The laboratory service is identified as such and eliminated by adding 10 more sessions. These simulation results are implemented and the simulation model itself is used as a decision support tool for further assistance to the management (Moreno et al. 1999).

General Hospital Resources Management

An investigation on the impact of the bed occupancy level on the inpatient bed crisis is undertaken with a discrete-event stochastic simulation model at a hypothetical acute hospital in England. Results show that hospitals operating at bed occupancy levels of 90% or more are likely to face regular bed crises. Hospitals with a bed occupancy level of less than 85% generally avoid a bed crisis as well as the associated risks to patients. Management should therefore plan interventions on a long term basis to match future demand growth (Bagust et al. 1999). This identified threshold of the occupancy level was quickly acknowledged by the NHS in 2000 (Bourn 2000) and was soon introduced as a rule of thumb recommendation for hospital managers (Proudlove et al. 2007). This was done without providing signs whether a generalisation is applicable to the original model and transferability to other hospitals is feasible. (subsequently revised to 82% (Department of Health (DoH) 2001)).

In the following simulation project, the authors identified that up until to 2002 it was common to estimate the capacity requirements for hospital beds using the average LoS figures in the Royal Berkshire and Battle Hospitals NHS Trust in Reading. In order to support the hospital management in their decisions on bed usage and patient flow, a tool based on simulation is designed which uses several programs such as the simulation shell – TOCHSIM and the data collection tool – Apollo. The designed simulation tool allows a more accurate interpretation of the current usage of hospital resources. This is achieved via a flow model of the patient routing through the whole hierarchy of the hospital. Scenarios are used to illustrate the consequences of possible decisions by the hospital management. It is shown that the previous LoS estimates are misleading in the interpretation of the current capacity situation. Instead, applying the tool allows forecasting future bed requirements and categorising of patients. In addition, quantifying the effects of combining speciality bed-pools, helps to depict capacity simulations more accurately. Moreover, using this simulation tool enables forecasting the effect of a change in admission policy and hospital extension (Harper 2002).

Another case study on patient flow and allocation of resources within a general hospital has been conducted by Vissers (1998). Until then, the hospital management of certain hospitals applied estimates from previous assumptions in order to manage the utilisation of resources. Vissers (1998), instead, uses a mathematical approach for the patient flow and builds a resource model. Patient records are extracted from the hospital database and are integrated in these models, which are validated with a detailed sensitivity analysis. The case study results in a comprehensive decision aid for either the reallocation of resources or the reduction of LoS. It is concluded with the description of the "Time-phased Resource Allocation" method. This method considers the correct level of allocations with the correct balance between allocations of different resources, avoiding capacity loss, as well as the correct timing and avoiding unnecessary peaks and troughs (Vissers 1998).

A more general study, which is applied to a general hospital, is recommended as a framework to other modellers. The benefits of the suggested framework are the development of detailed integrated simulation tools for the planning and management of hospital beds, operating theatres and workforce needs (Harper & Shahani 2002). To reflect the hospital dynamics, a flow model based on continuous modelling is chosen whereas the input for the model is classified by using the CART regression tree analysis, which allows a categorised and therefore detailed view of the patient records. Overall the framework illustrates the issues for modelling healthcare facilities. The case study which is used to demonstrate the benefits of this framework may lead to a flattened occupancy rate, which utilises a 2% higher patient throughput and a drop of the overall surgery refusal rate from 5 to 3% (Harper & Shahani 2002). The results of this study are implemented in practice.

Cardoen & Demeulemeester (2007) present a project which uses integrated patient care pathways to derive the simulation model. The project is dedicated to two case studies, the first was conducted at the Middleheim hospital in Antwerp and investigated the consultation and surgery unit of the hospital. The second was the catheterisation facility of the university hospital of Gasthuisberg. The use of integrated care pathways eases the development of the simulation models because the path of the patient is already well documented and relatively easy to derive and to integrate in a simulation model. Integrating these paths in a simulation model guarantees that the model replicates the behaviour of the clinic. Investigation on the model shows the effects of the changes in the bed capacity on bed utilisation. In this particular study, unused bed capacity is freed due to the findings of the simulation model (Cardoen & Demeulemeester 2007).

Patient Assignment / Scheduling

A novel nurse- patient assignment programme is developed on the basis of the data provided by Baylor Medical Center at Grapevine TX and Patricia Turpin. Sundaramoorthi et al. (2006) apply a stochastic simulation model (SIMNA) which is combined with a CART regression tree analysis to determine the transition probabilities for nurse movements to predict the amount of time spent at a certain location. To support their findings, validation is applied and the 40-20-40-rule is referenced McKay et al. (1986), which suggests that a modeller should spend 40% of the time on data analysis, 20% on the transition and 40% on the implementation of the model. This assignment programme assists nurses in making better decisions on nurse- patient assignments for a work shift. This results in a better care for patients, balanced workloads for nurses, and cost savings for the whole hospital (Sundaramoorthi et al. 2006).

Continuing with assignment tools, Vissers et al. (2007) introduce a platform which compares the performance of admission systems for hospitals. This theoretical model is built on assumptions and assumes a simplified hospital. The following admission plans are investigated: Maximum Resource Use (MRU), Zero Waiting Time (ZWT), Coordinated Booked Admission (CBA), and Uncoordinated Booked Admission (UBA). These different admission plans are then evaluated according to the resource utilisation of beds, intensive care beds, operating theatres, and nursing staff. Finally the paper proposes a contingency perspective to identify the most suitable admission strategy (Vissers et al. 2007).

Another assignment issue is concerned with the fluctuating demand loads in a rolling- horizon environment by applying overload rules and rule delay (Rohleder & Klassen 2002). Management chooses between the following overload rules: pure overtime, double booking from first to last or from the last to the first, double booking every fifth slot. The overbooking rules are combinable with the three rule delay options: simply none, or the one and two day delay. The combined rules with the overload options identify the best mix of rules. It is emphasised that the application of these results depends strongly on hospital idiosyncrasies and the patient demand. This paper identifies methods for minimising client waiting and server idleness which are of significant value to practitioners.

An investigational study which incorporates the high uncertainty and variability of patient demand is undertaken at a typical UK hospital by Bowers & Mould (2004). A simple Monte Carlo simulation including the patient demand model is used to emulate the orthopaedic trauma theatre. The use of simulation shows that the scheduling of the trauma theatres is modified by accepting a higher risk of cancellation, which frees two additional surgery hours per week. These results when applied to a general hospital in the UK increase the overall performance by 13% per year on elective surgeries (Bowers & Mould 2004). These findings are published in a technical manner in the European Journal of Operations Research (Bowers & Mould 2004). In addition, healthcare management issues as well as implementation barriers are addressed in an article published in the Journal of Management in Medicine (Bowers & Mould 2002).

Simulation on Surgery Departments

The following project study focuses on applying a straight forward discrete-event simulation which considers the urgency of treating the patients. This model can be used as a twofold operational tool, first to match hospital availability, and second to consider the patient needs. Expertise of the medical staff has been determined to verify the accurateness of the model. This study focuses on the benefits of DES when applied in a hospital (Everett 2002).

DES is used in another study in order to compare the use of pooled list with scheduled lists. In contrast to scheduled lists, pooled lists are an assemblage of undedicated tasks for various workstations. A DES model is built, including the availability of surgeons for appointments that are also dependent on other clinic activities. The results of the paper show that approximately 30% fewer patients are waiting during weeks when no appointments are available under the pooled-list method (Vasilakis et al. 2007).

Surgical departments in a hospital located in Genova, Italy, are designed by applying DES (Sciomachen et al. 2005). This was done in order to investigate the performance indices with special focus on the productivity of wards in terms of utilisation rate, patient throughput and overruns, resulting in unplanned overtime for staff. Different scenarios are tested to compare the actual time table with initial schedule which uses a blocked booking criterion for weekly scheduling. The model considers a weighted priority rule, which depends on the time waited, pain or organic dysfunction status, disability, and disease. Another scenario to be investigated is the implementation of a pre and post recovery room. It is concluded, that applying the master surgery schedule reduces the waiting list and the number of overruns by around 25% and 10% respectively. The selection of the shortest processing time rule in comparison to the longest processing time rule reduces the number of overruns by 54% and the total overrun time by 30%. This leads to a general reduction of the average utilisation rate (Sciomachen et al. 2005).

A study is undertaken by McAleer et al. (1995), which investigates a multi theatre suite by applying an entity life cycle diagram with data derived from the hospital records, covering the time span of four "regular" weeks. The expertise of the staff is determined in order to validate the model. Common complaints by surgeons about the understaffing of porters are shown to be incorrect once the first results are retrieved. Other results suggest that the capacity of the recovery area should be increased, which allows the six suite theatre block to operate with minimum time delays between procedures (McAleer et al. 1995).

An outpatient surgery at the University of Iowa, USA, uses simulation to model their operating room utilisation, where the inputs of the model include different methods to determine when a patient will be appointed for a surgery. Algorithms similar to those applicable to the knapsack problem, such as the on-line bin-packing algorithms, are used to consider case durations, lengths of time patients wait for surgery, hours of block time for each day, and number of blocks each week. Scheduling strategies such as next fit, best fit, worst fit, and first fit are evaluated. With the evaluation of these strategies it is concluded that a mean waiting time of 2 weeks for treatment is a reasonable goal (Dexter et al. 1999).

At the Children's Hospital of Philadelphia, USA, a study focuses on the determination of the optimum operating room utilisation. Under the investigation of several schedule policy schemes, it is illustrated that a reduced variability of durations of operations increases utilisation, while higher variability allows less utilisation to meet the target for patient delay. To consider these fluctuations it is concluded that the operating room is used most efficiently when utilisation is between 85% and 95% (Tyler et al. 2003).

2.3.4 Review on Simulation applied in Emergency Departments

However, healthcare managers may perceive barriers to the use of simulation: besides the terminology gap and communication issue between the modeller and the healthcare managers (Lowery et al. 1994), the biggest obstacle to overcome is that applying simulation is a time consuming process, compared to other solution finding techniques applied in operations research (Banks et al. 2005). In order to overcome the time issue, a proposal is made for the development of a framework, which delivers a template to enable the rapid development of a tailor made simulation for EDs.

The latest applications of DES to EDs show a high variety of possible application fields, including capacity planning, scheduling of staff and resources, and general conceptual planning for future development of the facility. One example displays how capacity planning can provide an efficient patient flow (Bagust et al. 1999) by calculating the maximum occupancy level of beds. To level out the peak of resource utilisation, the arrival pattern of patients is identified, which allows a significantly better planning of staff and resources (Sinreich & Marmor 2005*b*). A similar study enabled a reduction of patient turnaround times (Sinreich & Marmor 2004*a*). Simulation also proved to be of great potential for the future development of an ED in Istanbul; an extension plan is developed, which also increases the understanding of the processes involved within the ED (Kuban Altinel & Ulaş 1996). A major benefit of DES is that scenarios can be tested by stating ”What-If ”-questions. In one particular study, scenario testing allowed the development of a new ”fast track” lane within the ED which absorbed a third of all patients (Blake & Carter 1996). DES also offers interfaces for optimisation techniques, as for example genetic algorithms. These enabled Yeh & Lin (2007) to reduce patient queuing time by an average of 43%.

As indicated in the introduction (Section 1.1) the situation of EDs in Ireland is very severe. With long waiting times and high utilisation, the relationship between overcrowding and mortality rate challenges healthcare decision makers in Ireland. In order to improve the situation the HSE introduced a target in January 2009 which is now consistently used in Irish EDs. This target aims to keep the LoS of patients below 6 hours (Buckley 2009). The LoS here is in conjunction with the common definition of LoS which is the time spent from registration to admission or discharge. In the same report, the average waiting time for admission from ED to the hospital is compared with data from the period January to May 2008 with the same period for 2009. Indeed, an increase is indicated in the number of patients waiting 12 hours or more – in 2009, 46% of patients waited for longer than 12 hours or more (The Irish Society for Quality and Safety in Healthcare, Royal College of Surgeons in Ireland and Ipsos MORI Ireland 2007).

For the sake of simplicity, it is wise to consider the degree of complexity and to bear in mind that abstract models may well be sufficient to solve the underlying problems. However, as attractive as abstract models are, there is a the possibility that *the big picture* might be missed in certain circumstances in comparison to a comprehensive simulation model. An example for a comprehensive model is the ED-SIM (abbreviation for Emergency Department SIMulation) (Connelly & Bair 2004) model which is built in ExtendSim v.5. It is mentioned in Table 2.2 on page 50 as a very comprehensive model but its properties could not be obtained because there is only a description via text available. EDSIM considers the following features of an ED: triage, prioritisation, several staff level types. Typical according processes are also considered which represent imaging studies, laboratory studies, history and physical examination, nursing activity, consultations, and bedside procedures. The model however does not consider any different resources to human resources, which limits the investigation in case of supply shortages. In addition it can be seen that staff activities, which are off site from the patient, are not considered.

Modelling the complex behaviour of an ED is a challenging task, due to interaction of human and physical resources. Medical staff, for example, are rarely dedicated to one patient or task; instead they treat several others while waiting for other processes. This diversity of process interaction can be described as multitasking, a common feature of ED operations. Yet, multitasking is rarely considered in DES models of EDs (Günal & Pidd 2006). Several tasks and processes, depending on certain resources, result in interrupt-driven system behaviour demanding a well adjusted allocation of human and physical resources (Wild et al. 2004). The impact of multitasking on ED simulation models is worth further investigation, especially on the background of scarce shared resources. The effects of multitasking on any human resource within the model are more easily investigated with the introduced modules and are quicker facilitated than with ordinary process modules. A study on the stress impact on nurses is already facilitated with these modules and shows mathematical regularities, which are derived from Queuing Theory (Thorwarth et al. 2009).

A combination of the dynamics of the DES model and the static description with role activity diagram, is applied to describe the activities in an ED of a Mexican Hospital. This combination enables describing the process flow together with socio-technology issues. One of the major concerns of this study is to eliminate bottlenecks and the results predict a rise in throughput of 20%. This is achievable by capacity increase and elimination of bottlenecks (Martinez-Garcia & Mendez-Olague 2005).

This paper is provocatively entitled: "Looking in the wrong place for healthcare improvements: A system dynamics study of an accident and emergency department" (Lane et al. 2000, p. 518). The study uses system dynamics to simulate the interaction of demand patterns and ED resource deployment. Interfaces with other hospital processes and hospital bed numbers are also considered as well as the impact of variation on output policies. There are two conclusions: first a selective stock-up of resources reduces unavoidable waiting times for patients, and second, the reduction of bed numbers in the hospital does not affect waiting times but directly affects the cancellation rate for elective patients for surgery (Lane et al. 2000).

A NHS Walk-in Centre is planned and designed with the use of simulation at the North Mersey Community National Health Service Trust. Simulation results show how a Walk in Centre could be managed alternatively. This paper offers a basis for discussion and suggests changes, for example, the publication of busy times at the centre in a local newspaper in order to reduce the rate of patient arrival at peak times (Ashton et al. 2005).

Measuring crowding in an ED is achieved by Hoot et al. (2008). The theoretical model is validated with patient data from an academic ED, which facilitates a patient tracking system. A sliding-window design validates the model, which ensures separation of fitting and validation data in time series. Measures like the amount of waiting patients, waiting time, occupancy level, length of stay, boarding count, boarding time, and ambulance diversion are used to apply Pearson's correlation and to achieve a forecast for the short term of eight hours (Hoot et al. 2008).

An application of Total Quality Management (TQM) concepts aided by simulation-animation is undertaken at an ED of Hospital Perea, Puerto Rico. The simulation analysis covers triage, insurance filling, doctor visits, laboratory, x-rays, ct-scan, recovery room, and respiratory therapy. Conclusions specify a list of the recent ED attributes which affect its performance: non-standardised job descriptions, insufficient number of doctors, nurses and equipment to service the demand, backlock of hospital admissions. All these factors interrupt a smooth patient flow (Gonzalez et al. 1997).

2.3.5 Generalisation of Simulation Models

Applying a simulation project involves a considerable amount of preparation and effort which consumes manpower and time (see Section 2.2.3 on page 46). Considering this background it is a sensible thought, that models should be reusable, or at least a framework should be offered that eases the required investment into modelling. Scanning the literature review by considering the timely investment it takes to model a healthcare facility, none of the reviewed authors have reused a model by different authors. This finding is supported by the latest literature review presented by Günal & Pidd (2010) who emphasise that the oddity of having thousands of

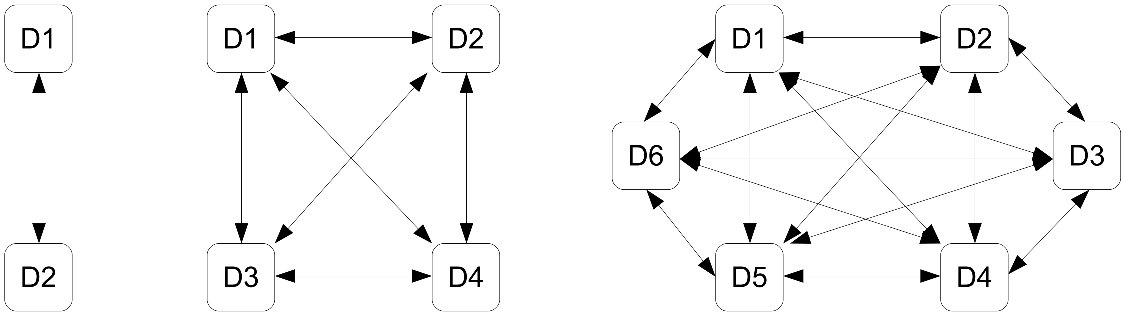


Figure 2.7: Communication channels with increasing number of participants. *Source: (Babich 1986).*

clinics and thousands of models accordingly.

The idea of reusing models stems from software engineering where it is a common and a standard feature: parts of a program are built and assembled in libraries, from which other programmers may access, use, and adjust to their needs. These libraries can be either public (accessible through the internet) or privately owned and protected by the specific developer. Throughout the decades, programmers have developed several revision control systems which help with development of programs and libraries. Concurrent Version System (CVS) is a good example for a tool that provides guidance and transparency for developers as it has been shown by Randell et al. (1999). They discuss its use by presenting case studies on large complex simulation models. Such a coordination guide is very valuable throughout the life cycle of a simulation project, by considering the increasing amount of communication channels among multiple modellers, as seen in Figure 2.7.

CVS is useful to achieve a coordinated cooperation among developers, but for model reusability it should be distinguished among several possible types of model reuse (Robinson et al. 2004): code scavenging, function reuse, component reuse, and full model reuse. Code scavenging describes the procedure of seeking and using some lines of apparently functional code to apply within the model. Function reuse is addressed on a larger scale in comparison to code scavenging as the search for a specific functionality such as a random number generator. Component reuse is based on locality and encapsulation, which is based on modularity (Pidd & Castro-Bayer 1998) and is influenced by the ideas of object orientated programming (OOP) (Pidd 1995*a*). The use of OOP as a tool within simulation modelling has previously been discussed by Zeigler (1987). The origin of OOP is based on SIMULA, which is a programming language to enable DES (Pidd 1995*b*). The concept of modularisation enables the building of large and complex models which are able to represent large structures. In current practice, the use of modules is common within simulation software packages, which enables the building of hierarchical blocks for easy reuse.

Considering the ease of reusability, it is surprising that in healthcare only few models were actually reused. Hence there are examples of reused models by the same authors. However, to the authors' best knowledge there has been no research carried out regarding the actual reuse of a model from a different author. A good example of reusability, transferability and evolution of a healthcare simulation model is provided by Kim & Horowitz (2002), Kim et al. (1999), Kim et al. (2000). The authors focused on the simulation of an ICU and evolved their model continuously according to new objectives. The first model represented the admission-and-discharge process, whereas the second model investigated several bed-reservation schemes. The last model on this particular ICU observed the advance-scheduling property for elective surgeries, where a daily quota system had been tested. Another example of generalisability is provided by Sinreich & Marmor (2005*b*), who exploited their model thoroughly by generalising to a very high degree. However, they achieved the generalisability with such a high degree of complexity that it appears almost impossible to rebuild from the model presentation within their paper. Discussions and advisories regarding reusability and generalisability are obviously more frequent than the actual use itself (Günal & Pidd 2010, Robinson et al. 2004, Swisher et al. 2001).

Presenting a framework is also a common way of offering a specific idea for generalisation. There are several authors who advise fellow researchers with frameworks, whereas one example stands out by advising how to build frameworks for operational modelling in hospitals, which has been established by Harper (2002). Within this paper the author provides guidance by illustrating which features and aspects the modellers should consider in order to provide a framework that can be used by other researchers. Thereby he addresses requirements such as flexibility and versatility, ease of use, internationality, and validity. In addition to this guidance, the author provides a case study, where he states an example towards his own guide, and how it would be used to construct a framework. This is a very general guide, which provides a check-list for future researchers to develop a framework.

A general methodology for the whole modelling procedure in healthcare facilities is proposed by Baldwin et al. (2004) and Eldabi, Irani & Paul (2002), who try to consider the specific features of the healthcare domain. They argue that the modelling methodologies proposed by Law & Kelton (2000) and Banks et al. (2005) are not directly applicable to the healthcare domain without considering the special features of the healthcare domain, such as the active role of the patient within the treatment process, as well as the high degree of complexity and uncertainty. They conclude that their approach helps to involve the stakeholders in the project and thereby achieve a higher degree of understanding with regards to the modelled system due to ongoing communication among the modeller and the stakeholders. This approach is rather abstract, but of high value throughout the modelling process, because the information gained by the modeller is fed back to the stakeholders.

As illustrated within this sub chapter, it is becoming apparent that reusability is still facing barriers. This is despite the fact that the necessary tools are provided within simulation software packages, theories are thoroughly discussed, and examples are stated. Reasons for this are provided by Robinson et al. (2004) who explains that models are built for several different objectives and hence the costs of adapting a valid model would be higher than developing a new model. This is especially the case when considering the need for adjustments and testing and whether a reused model component, by different authors, requires thorough testing. A solution to this problem would be to provide a certificate for tested model components similar to the way it is applied in software engineering (Monadjemi 2008). To acquire such a certificate would demand a high detailed documentation of the model component and also a detailed description of its interfaces. This certificate would reveal the transparency and thus improve the trust towards a component whilst also lowering the testing costs. To implement such a certificate a need would have to be identified as well as a market which could maintain the necessary infrastructure. Neither of these has yet to be established.

A different approach is emerging from the current healthcare environment, once a closer glance is taken at HIS providers such as SAP IS-H (Siemens AG 2010): their software provides all information necessary to build patient pathways, but instead of building a separate conceptual and simulation model, the models are defined by the data itself. Models are provided as templates for several different facilities. These models are adjusted to the needs of the specific healthcare facilities and also allow simulation and optimisation of staff scheduling (Jänicke & Müller-Lazarewski 2009). This automated procedure based on underlying patient data is a very promising attempt to build models. However, the degree of generalisation of the model templates defines the accuracy of the outcome of the simulation results. Hence where patient data availability is often an issue, here the validity of the model must be questioned. Some of these questions are rooted in the origin of simulation design, as for example complexity: Are the models capable of displaying and considering all relevant patient groups? Are scenarios tested on these models valid for adjustments to the real system? Are specific needs of certain facilities considered? What is the origin of the data – can the data provide the accuracy for all processes? The quality of a simulation model is crucially bound onto the quality of the data entered. As long as there is no quality control applied which checks that the data entered is sound, the generated model based on data is questionalble.

2.3.6 Implementation Issue for Simulation in Healthcare

Initially at the beginning of any simulation project, the aim is to implement promising results retrieved from the simulation model into the system under investigation. In order to maintain this target, the simulation modeller must ensure the trustworthiness of the model throughout the whole project. Trust is neither given nor granted, it must be established and maintained by successful management of the project. The client must also be kept up to date on the progress of the model (Musselman 1994). Eldabi, Irani & Paul (2002) have proposed an alternation to the simulation modelling procedure which gives guidance on how the communication channel can be well maintained among the stakeholders and the simulation modeller. Good preparation of the project is the first step to its successful completion. The more time which is invested in the problem formulation, and in the preparation for the data, the more trustworthy the model becomes (Eldabi, Irani & Paul 2002).

Even though there are many guidelines on how to construct and accomplish a good simulation research project (see Chapter 4), many projects in healthcare were not implemented. For example in the early 1980s Wilson surveyed 200 healthcare simulation projects, of which only 16 reported a successful implementation (Wilson 1981). Following this, 20 years later, Fone et al. (2003) reported similar results. This motivated the author to investigate recent simulation projects. Indeed, 97 recent publications from between 1996 and 2009 on simulation modelling in healthcare were investigated for any signs of result implementation. Thereby it should be mentioned that it has not been determined whether the implementation was successful. The mentioning of the application of the result was enough to take it into account for application. From all of the consulted publications it can be seen that only 29 projects were applied in various healthcare categories. Most were implemented in demographic healthcare provision and / or in outpatient clinics. Table 2.3 shows a summary on the recent publications and findings. Focusing just on the implementation for their intended facilities does not provide all the credit they might have deserved: it is worth mentioning that Baldwin et al. (2005) identified an optimum utilisation rate for hospital beds in order to even out peak demands. This utilisation rate has fast become a rule of thumb and a recommendation by the National Health Service (NHS) for all UK hospitals. Clearly, this publication example cannot be counted as a multiple implementation, but on the other hand it shows the impact of successful simulation studies.

Table 2.3: Implemented simulation results in different healthcare sectors.

Sector	**Author**	**Implemented**	**Implementation Ratio**
Hospital	Bagust et al. (1999),Cochran & Bharti (2006*b*),Günal & Pidd (2008),Harper (2002),Moreno et al. (1999)	Y	38%
	Gutjahr & Rauner (2007),Harper et al. (2009),Harper & Shahani (2002),Rohleder & Klassen (2002),Sundaramoorthi et al. (2006),Vissers (1998),Vissers et al. (2007),Vos et al. (2007)	N	
Surgery	Bowers & Mould (2002),Bowers & Mould (2004),Cardoen & Demeulemeester (2007),Dexter et al. (1999),Everett (2002),Jebali et al. (2006),Lamiri et al. (2008),Lehtonen et al. (2007),McAleer et al. (1995),Sciomachen et al. (2005),Tyler et al. (2003),Van Berkel & Blake (2007),Vasilakis et al. (2007)	N	0%
ICU	Sachdeva et al. (2007)	Y	14%
	Griffiths et al. (2005),Kim & Horowitz (2002),Kim et al. (1999),Kim et al. (2000),Litvak et al. (2008),Ridge et al. (1998)	N	
Miscellaneous Special Units	Cochran & Bharti (2006*a*),Elkhuizen et al. (2007)	Y	22%

Continued on next page ...

Table 2.3: ...continued: Implemented simulation results in different healthcare sectors.

...continued from previous page

Sector	Author	Implemented	Implementation Ratio
	Cardoen & Demeulemeester (2007),de Bruin et al. (2007),El-Darzi et al. (1998),Groothuis et al. (2001),Oddoye et al. (2009),Swisher & Jacobson (2002),Utley et al. (2003)	N	
Medical Imaging	Green et al. (2006),Patrick & Puterman (2007)	N	0%
Emergency Department	Blake & Carter (1996),Cooke et al. (2002),Fletcher et al. (2006),Kuban Altinel & Ulaş (1996),Mayhew & Smith (2008),Sinreich & Jabali (2007),Yeh & Lin (2007)	Y	24%
	Ashton et al. (2005),Baesler et al. (2003),Blasak et al. (2003),Bowers et al. (2009),Bowers & Mould (2005),Ceglowski et al. (2007),Centeno et al. (2003),Connelly & Bair (2004),Gonzalez et al. (1997),Hay et al. (2006),Hoot et al. (2008),Jones et al. (2002),Komashie & Ali (2005),Lane et al. (2000),Martinez-Garcia & Mendez-Olague (2005),Miller et al. (2004),Rossetti et al. (1999),Ruohonen et al. (2006),Sinreich & Marmor (2004*a*),Sinreich & Marmor (2004*b*),Takakuwa & Shiozaki (2004),Yeh & Lin (2007)	N	
Outpatient Clinic	Dodds (2005),Guo et al. (2004),Harper & Gamlin (2003),Huarng & Lee (1996),Wijewickrama & Takakuwa (2005)	Y	50%

Continued on next page ...

Table 2.3: ...continued: Implemented simulation results in different healthcare sectors.

...continued from previous page			
Sector	**Author**	**Implemented**	**Implementation Ratio**
	Alexopoulos et al. (2001),De Angelis et al. (2003),Robinson & Chen (2003),Rauner & Bajmoczy (2003),Vasilakis & El-Darzi (2001)	N	
Demographic Health Provision	Brailsford et al. (2004),Chu & Chu (2000),Harper et al. (2003),Harper & Shahani (2003),Rauner & Bajmoczy (2003),Rohleder et al. (2007),Vasilakis & El-Darzi (2001)	Y	47%
	Brailsford & Schmidt (2003),Davies et al. (2003),Katsaliaki & Brailsford (2007),Pasin et al. (2002),Paul et al. (2006),Ratcliffe et al. (2001),Roderick et al. (2004),Vasilakis & Marshall (2004)	N	
Haelth Care Supply Chain	Chu et al. (2003),Couchman et al. (2002),Haijema et al. (2007)	Y	75%
	Wijewickrama (2004)	N	

The implementation of simulation results is the final, yet may be hardest, challenge. Summarising the above publications during from 1995 to 2008 30% of their results are identified as having been implemented, compared to 8% which is reported by Wilson (1981) who reviewed approximately 200 papers published until 1980. This significant increase in the implementation ratio shows a higher acceptance for simulation as a solution technique for healthcare. Further recommendations for simulation modellers to overcome implementation issues are provided by Wilson (1981), Lowery et al. (1994), and Jun et al. (1999) within their discussion section:

- Recognition for the necessity of a change to the existing system;

- Total commitment of the modeller;
- Availability of data;
- Close communication;
- Credibility of the model;
- Response to deadline.

These key indicators given above, extracted from the discussion sections, do not guarantee a successful implementation. External reasons, caused by an unforeseen overall system change, may obsolete the necessity for the certain simulation study. One significant barrier is identified in Lowery et al. (1994) as: the terminological language gap between the modeller, who comes from an engineering background and the manager with the healthcare background. For example, if the modeller speaks with increased efficiency, it could be misinterpreted as a higher workload by staff. The overall contents of the implementation issue and its barriers are certainly applicable today, looking in the future, implementation reservations may be reduced because of the higher acceptance of applied computer technology. Simulation is a common approach for solution finding in military, manufacturing and logistics (Baldwin et al. 2004) and apparently healthcare providers poised to take advantage of opportunities in applying simulation as a solution finding technique.

Focusing on certain healthcare areas it can be observed that the highest implementation rate is in the healthcare supply chain environment with three out of four, while the lowest is in hospitals with 14%. It can be argued that first, three out of four is certainly not representative. On the other hand however, these facilities resemble manufacturing more, thus are more likely to adopt. In addition, hospital management is more restricted as they must ensure the safety of their patients. Figure 2.8 shows the implementation ratio for some elected healthcare sectors.

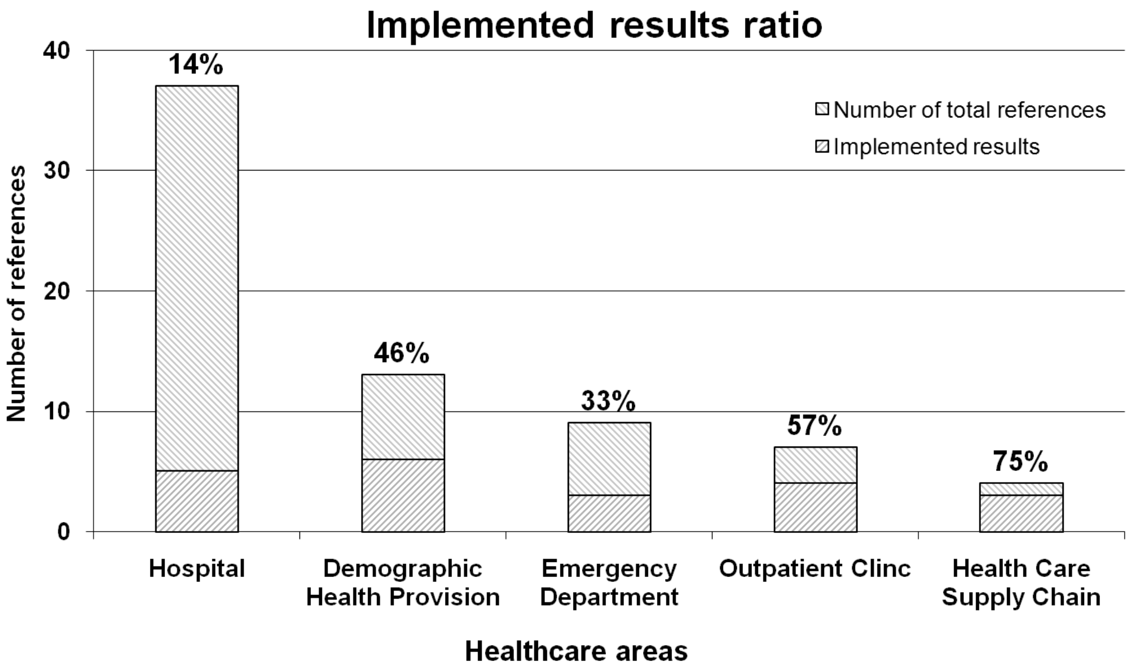


Figure 2.8: Implementation ratio of simulation in different health sectors.

Trust is also an important factor when it comes to the implementation of the results which are retrieved from applied DES models in healthcare. In consequence, it should be noted for this particular research, that trust can only be generated by communication. Drawn from these results, it is therefore imperative to consider a clear communication strategy where the content and agenda is prepared with consideration of all stake holders in order to minimise any misunderstandings.

2.3.7 Challenges of Simulation

DES has become a valuable addition to the decision support tools in hospital management. Long-term planning, for example the increase of the amount of beds or the investment in new diagnostic aids, can be made on a robust and sound basis. This is also true for short-term decisions like the scheduling of staff and resources or holiday planning. Potential applicants would therefore be those who have the authority to decide.

In general, DES offers a wide range of key features for analysing and mimicking the actual system (outpatient-clinic, hospital etc.):

- Experiments on model without interfering with the running system;
- Answers to "what-if...?"-questions that concern the management;
- Measurements and benchmarks for efficiency indicators such as length of stay and throughput time of the patient or utilisation of resources and staff;
- Scenario testing to improve process flow;
- Identification of bottlenecks;
- Optimisation applied on the model;
- Capacity planning;
- Investigations on certain phenomena;
- Investigation of correlations of variables;
- Integration of optimisation.

A computer based application allows variations of scenarios for decision making and planning. The decision maker has the opportunity to test scenarios interactively, for example an increase in patient arrival rate, a nurse strike and so forth. This will allow the decision maker to plan in anticipation. Integrated into the IT of the hospital, DES has the potential to assist forecasts on the length of stay of patients at certain stations, identify bottlenecks, and estimate over-or underutilisation, with the aid of data originating from the hospital information system.

However, healthcare processes are much more complex than manufacturing processes. Multitasking of doctors and nurses for example increases the grade of complexity additionally. Uncertainty of the patient arrival rate and of the patient treatments durations challenges discrete-event simulation.

There have been many misconceptions regarding process simulation, but healthcare was around to introduce this methodology as a solution finding technique. The main beliefs have been that the procedure, which is designed to model manufacturing is not suitable for healthcare, or that improving the efficiency will compromise the quality of patient care (McGuire 1998). Many were in fact speaking of the McDonaldisation of healthcare as it can be retrieved in Taylor & Lyon (1995).

Implementation is clearly an indicator for a successful project. However, it may well be that an unimplemented project is still successful by providing useful information and insights into the system, which allows the decision makers to make decisions on a sound information basis. This is especially true considering that simulation provides a comprehensive analysis of the system, which tries to consider as many aspects as possible.

2.4 Optimisation

2.4.1 Optimisation for Solution Finding

Optimisation on the simulated model helps to identify best possible settings with the available resources at hand which allow for improving system effectiveness. With the use of sensitivity analysis these results can be tested for robustness to assure, that the results are valid for a wider range of parameters. With this tool at hand, the decision makers can improve their service by maintaining the quality, or even making headroom for the resources which allow for an improvement of quality.

2.4.2 Evolutionary Optimisation

The purpose of evolutionary optimisation is to mimic natural evolution. The three main categories of optimisation all share common features in the way that randomness is inherited and that generations of populations are produced with each iteration cycle. A population describes the outcome of an iteration cycle which is a product of the trial solution with a random factor. Selection strategies, another common feature, determine which solution is maintained in future generations and which is removed (Fogel 1994).

These general features of evolutionary optimisation differ on their *application level* as for example the genetic algorithm, focuses on the variation of the chromosomes, the evolutionary strategies relate to changes in the level of the individuals and evolutionary programming deals with manipulation of the species (Fogel 1994).

The application level determines the different approaches regarding how the evolutionary optimisation methods are implemented. The genetic algorithm complies with the following sequence (Fogel 1994):

1. Assigning the problem to an objective function that indicates the fitness of a solution;
2. Trial solutions are initialised as a vector x and termed as chromosomes where its elements are named as genes;
3. A fitness score $\mu(x_i)$ is retrieved from the chromosomes x_i, $i = 1, ..., P$ of the population that reflects the objective;
4. Calculating the reproduction probability of each chromosome. p_i, $i = 1, ..., P$;
5. Production of "offsprings" for the next generation by applying genetic operators such as crossover and bit mutation;
6. Process repeats until a suitable solution is identified or a set computing time is reached.

The above illustrated algorithm is a general description for genetic algorithms which may differ in the application of selection methods like mutation. Applying a roulette wheel for example allows determining a strategy for the clipping of the genes (Houck et al. 1995). Applying this strategy provides a tool to guide the offspring of the parents. However, reproducing offspring in relation to the relative fitness does not guarantee asymptotic convergence to a global optimum (Rudolph 1994).

A modification to the genetic algorithm provides the evolutionary strategies, where the focus is set on the behaviour among the parents and offspring by spreading the parents' properties in an area similar to biological cultures. This can be achieved by following the procedure which represents one of the most simple evolutionary strategies (Fogel 1994):

1. Find the n-dimensional vector x for function $F(x) : R^n \rightarrow R$ containing an extremum;

2. Select an initial population x_i, $i = 1, \therefore, P$ within the feasible range;

3. From each parent x_i an offspring vector x_i', $i = 1, \therefore, P$ is created by adding a random variable (for example Gaussian with zero mean but with á priori selected standard deviation);

4. Select by evaluating the errors $F(x_i)$ and $F(x_i')$, $i = 1, \therefore, P$, where the P vectors follow the optimisation criteria with the least errors chosen for the next generation;

5. Process repeats until a suitable solution is identified or a set computing time is reached.

Generally, the evolutionary strategy is a robust optimisation strategy, yet presents two drawbacks: the first drawback is that setting a narrow standard deviation as a step size, slows down the convergence ratio significantly, and the second drawback is similar to the genetic algorithm in that identifying a global optimum cannot be guaranteed as populations can be "*trapped*" in a valley.

A different approach follows the evolutionary programming, which has the intention to include intelligent behaviour. This is achieved by providing parents with the ability to predict the development of the environment in time. They therefore consider this information for their reproduction strategy. This reproduction strategy is in conjunction with the objective function. To apply this strategy in an algorithm, Finite State Machines (FSM) are facilitated (Fogel 1991). Bäck et al. (1993) provide an algorithm for evolutionary programming as well as for evolutionary strategy and enhance similarities and differences among the later two approaches. The main difference to evolutionary strategies is that evolutionary programming realises a stochastic tournament for generations of their population, while evolutionary strategies apply recombination operations with other species (Fogel 1994).

Evolutionary optimisation methods share similar properties, such as:

- Trial solution populations;
- Random alternations to the solutions (offsprings),
- Selection methods that determine the progressing strategy for future generations.

The methods introduced here show significant differences: genetic algorithms manipulate and apply their randomness on the genome level of the individuals. These individuals thus mimic natural trials by applying mutation, inversion and crossing over. Evolutionary strategies and evolutionary programming emphasise the link between parents and offspring and their influence on the environment. Yet, the raw model of natural evolution is still applicable as it has proven over billions of years, both in terms of its robustness and its ability to adapt to a manifold different environment.

2.4.3 Optimisation Integrated in Healthcare Simulation

Due to the flexible approach of simulation, an integration of optimisation techniques is applicable. This is because all of the required data and models are already available with the simulation model (Banks et al. 2005). The following examples show the use of simulation models with a manageable amount of parameters. These models were then able to provide solutions for healthcare providers. A queuing network analysis (QNA), for example, is combined with a DES that enables a balancing of bed utilisation. The QNA identifies the bottlenecks within the system which can be widened by reallocating resources. The implementation of the case study resulted in an 8% increase in patient flow and a significant improvement of peak behaviour is demonstrated in smoothed demand (Cochran & Bharti 2006*b*). Another example addresses the optimum staff utilisation, which compares the Greedy Algorithm with the Ant Colony Optimisation approach. This case study is undertaken in a hospital in Vienna and uses values derived by a DES, specifically developed for this comparison. The DES includes a general cost function used for the optimisation. When analysing the optimisation results, it can be seen, that the ant colony optimisation achieves an additional cost saving of between 1 and 4% when compared to the Greedy algorithm (Gutjahr & Rauner 2007).

Productivity improvements at the surgery unit are the major concern of a study conducted at the Kuopio University Hospital (KUH), Northern Savo, Finland. For this study the surgery records of 2,603 patients are investigated and used for DES, including a linear regression model as an optimisation strategy. The linear regression model is used to forecast the schedule of the operating theatre and explained 46% operating time variance (Lehtonen et al. 2007). These are just a few illustrative examples of how optimisation techniques can be applied in healthcare. The following examples list optimisation techniques which are integrated in simulation:

- Integer Linear Programming (Rauner & Bajmoczy 2003);
- Mixed Integer Programming (Jebali et al. 2006);
- Monte Carlo Method (Lamiri et al. 2008);
- Genetic Algorithms (Yeh & Lin 2007);
- Markov Dynamic Programming (Haijema et al. 2007);

- Goal Programming (Oddoye et al. 2009);
- Queuing Network Analysis (Cochran & Bharti 2006*a*);
- Linear Regression Model (Lehtonen et al. 2007);
- Ant Colony Optimisation (Gutjahr & Rauner 2007);
- Scheduling (Harper & Gamlin 2003);
- Fuzzy-Logic (Khoumbati & Themistocleous 2007);
- Neural Network (Kilmer et al. 1997).

The application of optimisation in DES is well documented by providing various application guidelines (Andradóttir 1998, Bechhofer et al. 1995, Goldsman & Nelson 1998, Hochberg & Tamhane 1987, Jacobson & Schruben 1989, Nelson et al. 2001). With the advances of simulation packages in recent years, optimisation algorithms are added to these packages as further analysis tools, increasing the accessibility of optimisation for the user (Banks et al. 2005). However, a general problem remains: optimisation algorithms are either too specialised or converge too slowly for the application in practice (Fu 2002).

An approach to optimise the utilisation of operating theatres is to apply mixed integer programming in order to streamline surgery sequences efficiently. This is achieved by balancing the scheduled blocks. The model includes constraints and tests of 25 different scenarios in order to find the best utilisation. The authors highlight that further research should include the priority of the patients depending on their state of severity and the priority preferences of the surgeons (Jebali et al. 2006).

A theoretical study used mixed integer programming, which is integrated in a Monte Carlo simulation (Lamiri et al. 2008). The elective and emergency demand for surgical procedures is considered in the model to precisely reflect the variations in demand for the surgery. As an alternative optimisation strategy it is also proposed to combine this model with simulated annealing, taboo search, or genetic algorithm. However, proposing this methodology achieves a cost reduction of 4% (Lamiri et al. 2008).

A family practice healthcare clinic is used for the Visual Simulation Environment (VSE) based on object-oriented DES. The simulation model includes several statistical techniques like batch means, fractional factorial design, simultaneous ranking, selection, and multiple comparisons. Optimised results are obtained with the help of multivariate output analysis, such as ranking and selection or multiple comparison procedures. Included in the model to increase performance motivation, the clinics' fictional profit has been linked to patient satisfaction by introducing a financial penalty for each waited minute. This model gives a broad basis for decisions and discussion, especially when the quality of care and patient satisfaction is taken into account (Swisher & Jacobson 2002).

The effectiveness of an outpatient transfusion centre is investigated by using a methodology which interactively uses system simulation, estimation of target function and optimisation. As an optimisation strategy, Artificial Intelligence (AI) is applied by using Neural Networks and Radial Basis Function. As a base model, multiple servers and facilities are assigned to different services with budget restrictions. Although combining several complex elements, an easy-to-use system is developed with which the manager can evaluate the outcome of certain scenarios. The focus may either be set on the performance or quality level, each leading to different recommendations / results (De Angelis et al. 2003).

A statistical simulation model is utilised in order to optimise the bed balancing of a hospital. The aim of this study is to provide a decision support system that is more flexible than the previous ratio based decisions for the patient admission. As an objective function it is therefore targeted to minimise the standard deviation and the mean score for each number of beds in the model (Nguyen et al. 2005). The model itself appears abstract and uses bed numbers as a decision basis for its scoring – process relations are not considered within this model.

2.4.4 Optimisation of Emergency Departments

The investigated models on EDs only focus on certain aspects or procedures within an ED. This limited view is sometimes essential when the main objective is to optimise certain settings within the ED. Yeh & Lin (2007) for example, used a rather abstract model to apply a Genetic Algorithm technique in order to find a near optimal nurse schedule with the objective to minimise the patient waiting time. The focus of this study is on the application of this genetic algorithm, whereas the model of the ED is rather abstract: the patients' journey basically takes one route with only one exception which is the diversion after the triage which leads the patient to either bandage or emergency room. After this diversion the route is merged with the initial route. Diversity in EDs is generally much higher and it may be questionable whether it is wise to capture this diversity just with statistical distributions. Computational results regarding this model show that the average queue time can be reduced by 43% just by altering the nursing schedules without an increase of staffing level. Unfortunately it is not mentioned whether these results are actually implemented in the real system. An implementation would hence require a lot of trust by the management in the model, and the question is obvious, whether this is truly a representative model, once it has such a high abstraction level.

A multistage stochastic methodology is proposed in combination with QNA, optimisation and DES, in order to balance the inpatient bed unit utilisation of an entire hospital including the ED. In the first stage QNA and optimisation minimise blocking from the upstream units under the consideration of constraints on bed reallocation. In order to find an optimised setting, the objective function is chosen to minimise the Absolute Deviation (AD) of bed utilisation. After the optimisation is completed, a DES model is used to maximise the flow through the system and to retrieve KPIs of the changed system. The case study resulted in an 8% increase in patient flow with this multistage methodology (Cochran & Bharti 2006*b*).

A more visual approach for non-experts of staff scheduling optimisation is chosen by Centeno et al. (2003) where the staffing demand for the ED is presented in an visual basic interface. The optimisation is applied with ILP where on the particular model an improvement of 34.40 in the total person-hours could be achieved, resulting in an overall improvement of 28%.

Optimisation may also be applicable via direct comparison of results: Rossetti et al. (1999) for example uses the Bonferroni Analysis in order to compare a particular result with a grouped result. With this methodology, the *overall winner* is rapidly evaluated.

Optimisation is manifold applicable either as a combination with simulation or as an integrated solution within DES.

2.4.5 Limitations to Optimisation

Another aspect which has not been covered in depth by the recent literature is that by integrating optimisation the level of detail may be reduced. This results in a lower representation of the model. Therefore, the obtained solutions are rarely able to reflect reality or are highly questionable. Multi-objective optimisation can be utilised which is described as finding the best trade-off among several solutions. An example for a systematic approach in order to find the best trade off is presented by Nebro et al. (2008). They apply a scatter search algorithm in order to find the best possible solution. It would be worth investigating and evaluating which optimisation strategy is most suitable for a complex simulation model that represents the behaviour and uncertainty of an ED. However, only a few models consider multitasking of resources which is a common and essential operation in EDs, thus this research offers avenues for further research.

2.5 Discussion

Reviewing literature on healthcare systems highlights that every nation is constantly striving to improve their healthcare system. Indeed any potential optimal system that is identified must be suitable for the cultural needs and demands of a nations' citizens. Identifying an optimal system and transferring it to different cultural backgrounds is an infeasible approach. However, elements that indicate a promising improvement, may be adopted by a different country.

Diversity in healthcare is primarily caused by unpredictable spontaneous demand and high variety which is inflicted by individual needs in general. In comparison to the industrial supply system, the healthcare system must consider the human factor, which poses a challenge to managers of healthcare facilities.

One challenge for healthcare facility managers, especially in Ireland, are the EDs: high demand and high utilisation indicate a reason for concern in the context of overcrowding, which is related to increased mortality rates in Australian EDs. Waiting times and LoS in Irish EDs are above the acceptable measure (6.5 hours average wait for treatment (Regan 2000) – those numbers have yet not improved, as can be seen from reports of HCP and HSE. Performance targets and assessments of the current system are the first steps to create an awareness of the problem. The current Irish economic situation is unfortunately not in the best condition to promote investments in the healthcare system. Therefore, a sustainable solution, which eases the burden of healthcare managers, is not yet in sight.

EDs in Ireland are positioned between the primary and secondary care services, therefore EDs are in a position where high expectations from patients on one side and healthcare providers on the other side result in pressure. This position imposes a duty to fill the gaps of both the primary care and the secondary care sectors. Gaps and issues of the primary system are highlighted by the Department of Health & Children (DoHC) (2001), where the inadequacies are listed. The healthcare strategy back in 2001 noted crucial difficulties in the Irish healthcare system that impinge on the performance of EDs:

- Poorly developed primary care infrastructure and capacity;
- Potential to reduce pressure on secondary care not fully realised;
- Secondary care providing many services which are more appropriate to primary care;
- Out-of-hours services underdeveloped;
- Limited availability of many professional groups;
- Communication between professionals and sectors inadequate.

These concerns are still echoed in the more recent Comptroller and Auditors Special Report on Emergency Departments (Buckley 2009) which outlined some of the key difficulties for EDs in Ireland; firstly Emergency departments cannot operate in isolation from the wider hospital. Their effectiveness is tied into the way that the overall hospital in which they function is organised in terms of discharge planning and overall capacity. Secondly, there is heavy reliance on EDs due to limited primary and community care services. The primary care service as represented by out of hours GP services has very poor national coverage and availability.

These issues lead to increased pressure and demand and high variations in the demand for EDs as they are responsible for the provision of a wide range of healthcare services. The additional demand therefore increases the pressure for EDs and facility managers strive for solution techniques that identify improvement potential on operational level and on strategic level.

A promising approach to facilitate improvements on the operational level is the application of process flow simulation, adopted from industry and logistics. Here a focused investigation of the processes is combinable with the introduction of clinical pathways that are introduced in the context of DRGs for a healthcare facility. From the perspective of process flow analysis, the introduction of the clinical pathways, supplement the description of process flow as an As-Is- description of the current work flow. Retrieving this description would be an ideal starting point for the conceptual model which could later be used in the translation of the simulation model.

Simulation of healthcare processes allows for the asking of "What-If "- questions regarding the system under investigation without interfering with the running of the system. Once a scenario is sufficiently tested and approved, the recommendations retrieved regarding the analysis phase can be implemented into the real system with a high level of confidence and with control over the risk. Experimenting with the running system is potentially harmful, as patients lives may be at stake.

The amount of research undertaken into simulation as applied in healthcare has risen significantly over the last 15 years. Many of these simulation models have made a significant improvement to the certain applied facility. This success can be contributed to the analytic approach of simulation studies: an intensive analysis of the system under investigation is necessary so that answers may already be obvious in the analysis phase. However, the simulation study can then confirm the initial suggestions for improvement and deliver an estimate of expected improvement.

Simulation has shown that it has a great deal of potential with regards to improving healthcare processes and facilities. However, it also has its limitations: simulation can replicate a system in certain boundaries, but it cannot suggest what the best parameter setting for the investigated system would be. Due to the flexible approach of simulation, the integration of many optimisation strategies are possible, which hence delivers optimised solutions for the desired objective function. The applied optimisation methods can consider simple gradient search functions up to more sophisticated evolutionary approaches. Optimisation supplies simulation with a tool set that enables it to provide solutions.

Within the literature review, simulation has shown many advantages and provided good arguments for its application in healthcare. However, barriers for its application are apparently tethered to complexity: as healthcare processes tend to be complex, building replications of complex systems are a time consuming process. This delays the delivery of results derived from the simulation project. Due to this delay in the delivery of results, the project might face the risk that it is becoming obsolete over time, as the initial setting has changed, which may eliminate the basis for the study. Another barrier tethered to complexity is that the simulation models are difficult to maintain and that later required changes to the model, may be difficult – if not impossible, due to the lack of documentation and expertise. Due to these reasons, simulationists tend to apply simpler models, which are easier to maintain and the results are deliverable earlier. Simpler models, however, are just a shadow of reality, and might miss certain important details which have a significant impact on the precision of the results.

On the background of complexity, a consideration of the reuse of simulation models is an appropriate measure to reduce the time investment for the construction phase. There are already several theoretical approaches – based on computing engineering – available. However, *"Opinions vary about the value and feasibility of reuse (Robinson et al. 2004), but it seems hard to imagine that 1000 outpatient clinics require 1000 different simulation models."*, (Günal & Pidd 2010, p. 49). Frameworks are developed which provide guidance for simulation modellers, who intend to build a simulation model applied in healthcare, an example of such a framework is provided by Harper (2002).

Simulation is applicable to many areas within healthcare, but surprisingly only 30% of the surveyed papers mention an implementation in the healthcare sector. The following areas show a different implementation ratio (see Table 2.4): the high-

Table 2.4: Implementation ratio of simulation applications in various healthcare sectors (summary drawn from table 2.3 of page 86).

Sector	**Implementation Ratio**
Surgery	0%
Medical Imaging	0%
Intensive Care Units	14%
Miscellaneous Special Units	22%
Emergency Department	24%
Hospital	38%
Demographic Health Provision	47%
Outpatient Clinic	50%
Healthcare Supply Chain	75%

est implementation ratio is observed in the healthcare supply chain with 75%; every second study on outpatient clinics indicates an implementation of results, whereas medical imaging units and surgeries are reluctant in accepting recommendations drawn from simulation results.

The healthcare sector is a sensitive field with high quality restrictions. In general, the introduction of a new technology or methodology must be harmless for both patient and applicant. In addition to this, the introduction must provide a certain benefit to the treatment processes. The purposes of simulation are manifold: either to increase the value of the simulated processes by increasing its efficiency, to show the applicability of certain process structures by simulation itself, or to identify certain relationships between processes. By the appliance of simulation techniques, results can be found which are worth being implemented. However, trust and confidence must also be confirmed for the user to-be. McAleer et al. (1995) make a critical statement about the implementation of simulation projects in healthcare:

> *"With regard to operational researchers the general attitude of hospital doctors appears to be – here is the problem, go and solve it and bring back the solution. However, even if they show little interest in the first place they show great interest in any proposed change. If they do not like*

the proposed solution it has no chance of successful implementation.”, (McAleer et al. 1995, p. 16).

2.5.1 Summary of Literature Findings

The literature review identifies the background of healthcare improvements, highlights the need for research in the area of simulation applications in healthcare, and briefs about work already done in this area. Healthcare is a complex application field, where products and services are not comparable to industrial goods due to the special nature of health itself. Healthcare economy is thus a special consideration of political decision on funding decisions, and cultural background of societies for health expectations. To illustrate the scope of healthcare economics, a brief summary on funding possibilities identifies various ways of financing the healthcare systems. Public funding is in general the most common way to distribute the costs solidarily among the society. To complement special desires and needs of patients, a private scheme is then often accessed as a supplemental measure.

To focus on the issues of healthcare challenges on the operational level, the Irish EDs are investigated as they present a reason for concern for the Irish public and politicians. Many EDs face a high demand, are highly utilised and present long waiting times for their patients. As overcrowding is identified to be related to mortality, the need for change is increasing. The economic situation in Ireland is currently not in a fit condition to promote costly improvement investments, thus optimisation on the operational level appears to be an attractive alternative.

EDs in general tend to be complex due to the high service variability. They must consider that any potential patient case has to be covered, or at least measures must be in place for a coordinated referral with minimum interruption and delay. To estimate the complexity in the context of process flow models, the ECyM is identified and acquired to compare several EDs. As an alternative proposal the EDC delivers higher increments than the ECyM and is thus an interesting alternative for complexity consideration.

Process flow models are the basis for simulation models – often DES – applied in healthcare facilities in order to improve the operations. Simulation has shown a high potential for improvement and its application is increasing in popularity. Improvements impact on the reduction of patient waits or the optimised supply of resources. These improvements are addressed in journal papers which deliver a recommendation derived from simulation and optimisation results. Although the potential improvements are promising, the implementation of these results is still very low in some healthcare sectors, as for example in surgery and medical imaging where it is rare to identify statements of implementation within the publications. Trust in results is a task yet to be established among healthcare managers.

This discussion section closes the literature review and summarises the significant aspects which are essential for the consideration of process simulation applied in the sensitive domain of healthcare.

2.5.2 Research Gaps Analysis

The review highlights that simulation in general and DES is a highly adjustable tool, which can be applied in various fields within healthcare. Investigations on the staffing level, the right scheduling, or the identification of bottlenecks are possible and became a common practice, considering the growing amount of publications in this field. However, due to the high degree of complexity and variability that is inherited within this field, publishers tend to build rather clearly laid out models with a limited degree of complexity (Günal & Pidd 2010). Abstract models are justified for various reasons:

- The time required for the development of an abstract model is manageable and keeps the model up to date with the current problems which are under investigation;

- The error rate is kept low and debugging effort can be easily maintained;
- The verification and validation is easier to manage.

However attractive simple models appear, they do not consider certain details, which may be crucial. The reviewed simulation models applied in healthcare tend to be simplistic. The 22 investigated samples are the only ones which allow an estimation on ECyM and just four of them consider a high degree of detail ($ECyM > 20$, see table 2.1 on page 47). Sinreich & Marmor (2005*b*) for example considers a relatively high degree of detail and also employs different staffing roles in order to design a representative model of an ED. Yet, there is no sign of any interaction between the different staff roles. A common sight in a highly utilised ED is the Flexible Allocation of Resources (FRA) where, in emergency cases, a staff member spontaneously substitutes for another staff member who is occupied in a different process. FRA, is yet not described in any healthcare simulation model to the best knowledge of the author.

The illustrated models (Table 2.2 on page 50) rarely allow an insight into how the resources are used. The most common case among the investigated models is that one resource is allocated to one patient, whereas different resources are rarely considered. In a heterogeneous environment, such as an ED, it is important to consider various levels of supply. Shortages on supply can appear on many levels such as staffing, devices, medicine or even other relevant services like catering for patients. In order to identify such shortages, a higher degree of complexity of simulation models is required.

Focusing on the healthcare process simulation, there are simulation models which describe either the patient pathway, or describe the work flow of medical staff. A combination of both has not yet been identified in the current literature. A source where such a description would have been assumed at least in a theoretical description would be Zeigler et al. (2000). A consideration of the patient pathway in accordance with the workflow of staff would be a sensible thought, especially once the complexity of work applied to a patient is regarded. A process involving a patient, requires preparation and also post-processing, such as documentation of the explicit medical staff member. Within the literature review, it can be seen, that models focusing on the simulation of the patient pathway, ignore the workflow of the medical staff involved.

Inserting the work flow within the patient pathway in a simulation model and considering FRA would inject a higher degree of reality and precision into the model. Considering both would significantly increase the degree of complexity of such a model, and yet, there is no study recorded which considers these. The reason for this may be, that the complexity involved in such a system, would exceed the manageable scope of the modellers. However, without such a system, phenomena which would have an impact on the patient pathway as well as on the workflow of medical staff cannot be investigated with satisfactory results. A toolset may be required which enables the modeller to guide himself through the complexity of such a system that considers FRA and multiple participants within a model.

Although several frameworks for healthcare in general and hospitals exist (Ashton et al. 2005, Bagust et al. 1999, Blake & Carter 1996, Gonzalez et al. 1997, Hoot et al. 2008, Kuban Altinel & Ulaş 1996, Lane et al. 2000, Martinez-Garcia & Mendez-Olague 2005, Sinreich & Marmor 2004*a*, Yeh & Lin 2007), a framework which considers the special environment of an ED has not yet been developed. In a different domain, however, some examples can be retrieved that consider several proposals of simulation frameworks for hospitals (Bard & Purnomo 2005, Chu & Chu 2000, Gutjahr & Rauner 2007, Harper 2002, Vissers et al. 2005, Vissers et al. 2007). These frameworks can be used as a role model for frameworks which are applied in EDs. A guideline for simulation framework in healthcare can be obtained from Harper (2002), which is initially intended for hospitals. However, an integrated approach for PDSS in the context of FRA and MPPM could not be identified to the best knowledge of the author. Such a framework would allow a reduced development time of simulation models in healthcare facilities, and would also increase the trust by healthcare managers as these models tend to consider a higher precision of the replicated system.

2.5.3 Conclusion on Literature Review

Simulation studies applied in healthcare enjoy a high focus in research and practice. It's flexible approach allows simulation to integrate with optimisation for solution finding and the adaptation to various different healthcare sectors. Yet, the replication of healthcare systems either focuses on the patients' journey through the healthcare facility, or investigates the workflow of medical staff. A combination of both is yet not observed. Complexity is identified for a potential reason. Therefore a framework guides the simulation modeller through the design process in case scenarios arise which impact the work flow as well as the patients' journey. In order to design appropriate models, a structure and a methodology is proposed in order to facilitate the modeller with tools that help him to accelerate the development of complex models. In order to offer these tools to a broader public, the principles of these tools are laid out in detail, thus an application to any appropriate simulation is guaranteed.

One of the core features of healthcare is its inherited complexity. This complexity is due to the diversity of the patients. Once a healthcare facility is not specialised on only certain patient groups, a trade off must be reached in order to reduce the complexity, otherwise the modelling process becomes increasingly time consuming. The consequence would therefore be that the models are highly abstract and in effect are a shadow of reality. It is therefore questionable whether high abstract models are truly representative and a great deal of effort must be invested in order to convince the stakeholders of its accuracy.

The literature review identifies that process simulation has achieved a high impact on the operational improvements of healthcare facilities. However, complex issues are addressed which present a barrier to the implementation of recommendations derived from simulation studies.

Chapter 3

Research Methodology

Mankind strives to identify explanations for the nature of things, or find an understanding of mechanism with complex relationships. This understanding helps to plan, structure and develop patterns which hence minimise the perceived impression of randomness. This aim is a first attempt at a structured approach intended to create a routine or a procedure which allows constant improvement. An example which is applicable here is that of astronomy which generated calendars. This led to a better scheduling for seeding which hence resulted in a higher outcome of the harvest. In order to retrieve these results in an orderly manner a certain structure was required in the pursuit of true knowledge. One of the first names that arises is Aristotle, who is considered as the founder of the modern science (De Lacy O'Leary 1949). However, development of the scientific methodology, as we know it today, can be traced back to Ibn Al-Haytham:

> *"Truth is sought for its own sake. And those who are engaged upon the quest for anything for its own sake are not interested in other things. Finding the truth is difficult, and the road to it is rough."*, (see Alhazen (Ibn Al-Haytham) 1962) as referenced on p. 139 of Sambursky (1974).

With this statement it is apparent that research methodologies are under constant reassessment and that alternatives will be essential once the science community has discovered flaws in the current methodologies. It is also evident that there cannot be an overall research methodology for all existent research fields, thus research fields have adapted the scientific method to their needs. Examples of relevant sciences are natural science, social and behavioural science, applied science and formal science. The latter describes formal systems as a branch of knowledge, as for example logic, mathematics, computer science, statistics, decision theory etc. The procedure for conducting simulation research projects, for example, is primarily based on methods deriving from formal science. However, in building simulation models, which is an interdisciplinary topic, researchers may like to access other research techniques. Such research techniques may derive from social sciences like quantitative or qualitative research methodologies or even an integrated combination of both as a mixed method approach, which allows combining the quantitative and the qualitative research methodologies, in order to benefit from their advantages.

Of particular interest for this dissertation, which focuses on modelling approaches for DES as a decision support tool for healthcare, is the contribution of Eldabi, Irani, Paul & Love (2002). These scholars have have highlighted common characteristics of DES – mainly known as a quantitive research tool – for the qualitative research methodology.

Within this chapter, the two utilised research methodologies – quantitative and qualitative – are introduced and laid out as both are required in order to conduct this research. This research is differentiated among primary and secondary research, where the primary research is fieldwork, for which both research methodologies are combined, and the secondary research identifies the research potential by applying the literature and the work already existing within academia. To create a common basis of understanding, the research methodologies are explained, before the actual structure for this research is planned and laid out. Due to the flexible and interdisciplinary approach, the research methodologies are a necessary requirement for the application of the research methodology selected for this research.

To conclude this chapter, the way in which the procedure to the build simulation model fits with the research methodologies is discussed. With this target in mind it is discussed how the formal reasoning applied in formal science can support the simulation approach. In addition, how the quantitative and qualitative research methodology can be accessed in order to retrieve valuable information for this interdisciplinary research is also highlighted. This chapter will conclude with a hypothetical discussion on DES and its potential contribution as a research methodology.

3.1 Qualitative Research Methodology

Conducting research within social science is commonly guided by three methodologies: the quantitative methodology, the qualitative methodology and also the mixed method approach. The qualitative methodology follows the interpretivism approach, which focuses on understanding and attaching a meaning to phenomena which originate from the interaction among social individuals within their context. The aim of an interpretivist is to identify axioms and events that lead to a certain behaviour. A common exploration technique is an empirical strategy based on "face-to-face" interviews, where the researcher retrieves qualitative information, which is not quantifiable as such, but interpretable, due to identifying reasons for the certain behaviour of the subject under investigation. A proposed guideline for qualitative research design is presented by Pickard (2007), which is adapted from Kumar (1999), and Lincoln & Guba (1985). Although a straight forward procedure is implied, it is important to note that the research design plan cannot be followed in detail to the proposed procedure – rather, it is "played by ear", (Lincoln & Guba 1985, p. 203) which is instilled by the proposed procedure as a framework for involvement.

According to Pickard (2007), a qualitative research design is initiated by identifying the research field, or the observation of a certain phenomenon in a particular topic of interest. The researcher hence creates a theoretical framework according to the findings of the literature review, which details the phenomenon. Based on the theoretical framework and the literature review results, a conceptual framework is designed which provides guidance with a view to answering the research question and research objectives. The final output at this stage is the research proposal, also containing and considering foundations for an ethical approval for the research.

The qualitative data can be obtained via interviews from experts. In the example of an ED, the experts are those who work in the ED – doctors, nurses, consultants, administrators and managers. However, depending on the role of the expert the information provided may differ and be biased due to the different perspectives of the employees. Also, not all information may be true as the employee may be afraid that the information provided might be used against him. Anonymous interviews should therefore be guaranteed. However, it is advisable to identify those persons who are particularly knowledgeable in order to increase the credibility of the acquired data.

This conceptual framework provides a roadmap for the interviewer with an inquiry strategy which is considered as the research object, usually a human taken from a population which is representative for the investigation. These instructions contain purposive sampling, data collection (visual, verbal and written), inductive data analysis and grounded theory – these steps are repeated until sufficient data is collected.

In the concluding research phase the outcomes are negotiated and the case report is verified with study participants before presenting a working hypothesis. As mentioned in the elaboration of the proposed procedure provided by Pickard (2007), it should be considered that this proposal is a general framework which must be adapted to the individual research question and topic of interest. An example of this can be seen for example, in the review on qualitative research for healthcare (Cohen & Crabtree 2008).

In general, researchers applying qualitative research are committed to investigate the actions and values of their subjects, whereby focus is set on a subjective perspective. This perspective implies that the impact of the bias must be clearly understood as well as being clearly isolated. In order to achieve this understanding the researcher must get 'close' to the subject and develop an understanding.

The strength of qualitative research is that it delivers an understanding of relationships. However, on the downside there are three major weaknesses highlighted by Eldabi, Irani, Paul & Love (2002) which come with qualitative research and must be considered: one of these weaknesses is the large amount of written recorded data which is transcribed during the interview; this can overwhelm the researcher. This weakness can be overcome by using computer software which helps the researcher for example by systematically grouping the common phrases that express certain opinions. Another major weakness is that it is very difficult to take the researchers or interviewers subjectivity out of the equation – it is therefore challenging or even impossible to identify a research design which can be reproduced. The third weakness is that the research may become isolated from theory as the researcher might not consider there to be a strong relationship between theory and practice.

Although qualitative research methodologies involves a lot of effort with regards to data compilation, its main strength is that it is flexible to unexpected insights during the actual fieldwork and data analysis. For example if new insights are apparent, the data acquisition can be extended for further in-depth analysis. This flexibility thus provides a thorough understanding of relationships for the object under investigation.

3.2 Quantitative Research Methodology

While interpretivists try to understand the relationships of events and the triggers to certain behaviour patterns of an object under investigation, positivists focus more on the components of a phenomenon and aim to describe the relationship between these components during their investigation. Positivism is therefore a quantitative approach, as these components are quantifiable and measurable. Thus, the quantitative research methodology is more linear and direct than the qualitative research methodology.

The procedure to conduct a quantitative study therefore is set up as the following (Pickard 2007): the topic of interest provides the frame, where the study is applied. The literature review provides information about previous studies applied in this area, and also provides information that is useful to the research proposal. An established theoretical framework, based on the literature review, supports the researcher during the design of the study. Part of the research proposal is the conceptual framework, where the research questions are stated and the problems are defined. The main design part of the research must be set out in advance, as once the survey starts, everything must be considered and alternations to the research program are not possible. Subsequent to the research proposal, the variables to the phenomenon have to be identified and allocated. The variables aim to answer the question of how the components are assembled, so that the certain phenomenon can occur. The set of variables are hence the basis to define aims and objectives for the research and also to facilitate the creation of hypotheses which are to be answered with the help of the falsification method. Falsification is necessary as science does not attempt to discover the truth as such, but to illustrate what is not true. By identifying false statements, the researcher gets a better impression of what the truth could look like.

The quantitative data is either stored in computer databases, written on documents, or recorded. Access to the quantitative data may not always be easy because the content may be protected by laws and restrictions, and also because the data may be distributed over various systems. The quality of the data is also a crucial factor, as the simulation model is deeply reliant on it. The modeller has therefore to question the credibility of the data, and in cases of uncertainty, search for more reliable data or retrieve data specifically customised to the projects needs. However, perfect data assemblies that are without error are rare – technical failure of automated input devices, typos by those who input the data, are just some reasons for flawed data. For that reason, the modeller might have to apply statistical methods in order to eliminate outliers or to correct typos if possible. Data clearance is a wide topic (Schwertman & de Silva 2007), which shall not be discussed in depth in this research. A good overview regarding detailed issues on data mining in general for simulation studies is provided by Bradley, who also explains relevant data mining techniques (Bradley et al. 1999).

The quantitative research method is a linear research approach, which is relatively easy to control, as long as it is designed thoroughly with respect to the fact that once the survey is rolled out, changes are no longer possible. Another drawback is that the survey instrument must be designed in such a way that opinions are not triggered among the individuals.

In comparison to the qualitative research, the quantitative approach is considered to be more objective and that testability of the results in form of causality and replication is given. However, the quality of insight will not be as deep as the qualitative research. In order to provide an equivalent "insight level", follow up studies must be evaluated, which consider previous results and conclusions. At that stage the stakeholders should consider whether this additional insight is worth the effort.

3.3 Applied Research Methodology

This research is split into two main phases: the first phase consists of secondary research. During this phase, literature is reviewed in order to retrieve an overview of potential improvements in healthcare processes. The second phase is the primary research describing the fieldwork. In order to identify research opportunities, the secondary research is primarily undertaken and continued while the field work is conducted in order to identify the newest trends and developments. With regards to the fieldwork, quantitative and qualitative research methodologies are combined in order to follow an empirical approach, which is a suggested procedure and has been approved in previous simulation studies.

3.3.1 Secondary Research

To comply with the research methodology, the secondary research will be discussed and elaborated on in this section. Various sources are investigated and drawn into attention. First of all, and most importantly is the academic literature which encompasses educational and academic books. In addition to academic literature, reports issued by official institutes and healthcare facilities are accessed. The considerations which guided the secondary research are drawn from the main research motive while focusing on the secondary research. The following considerations are investigated while reviewing the available literature:

- The solution techniques which are applied in healthcare facilities to achieve an operative improvement.
- Lesson learned from the applied approaches.
- The most promising approaches.
- Transferability of the applied solution techniques.
- Limitations of the solution technique.
- Identification of a theory / practice gap.
- Potential for new developments in the domain.

The topics considered for this research were retrieved from literature on healthcare and from general academic resources, such as operations research applied in industry and logistics. Those topics accessed outside healthcare were general process modelling, simulation, augmented reality, animation, operations research, optimisation, supply chain, quality management, and risk management. In contrast, approaches already applied in healthcare are investigated in general healthcare facilities such as hospitals, outpatient departments, General Practitioner (GP) practices, supply chain for healthcare and demographic health distribution. The findings of this secondary research are laid out and displayed in the literature review section.

The primary area of interest is improvement in the operative healthcare facility. As many solution techniques derive from the area of operations research, these are investigated regardless of the application domain. Therefore the area of interest expands to cover the domain of industrial applications and also to cover applications in supply chain. The most promising approaches for the healthcare domain appear to be simulation approaches due to their flexible approach to include solution finding techniques, such as optimisation. It is becoming apparent that the primary area of interest is interlinked with other topics and domains, such as operation research, supply chain, logistics, simulation and optimisation. Accessing these topics widens the area of interest and leads to a continuous expansion of the area of interest as such.

Theory knowledge is obtainable from various academic books. The application domain of the identified books are not primarily relevant and are transferable to other domains. Theoretical articles are also obtainable from academic journals. A contribution or theory and practice is commonly found in academic journals, which considers the application of the discussed theory. In order to identify the current situation regarding the application domain, sources are accessed, such as reports from healthcare providers, hospitals or governmental institutions. Independent private institutes provide insights into the current state of the healthcare domain by delivering nationwide benchmarks or rankings. These are important insights that deliver measurements allowing for the consideration of improvement measures.

3.3.2 Primary Research

One way to achieve an understanding of systems is to observe them and study their mechanisms. This delivers knowledge of how the systems are reacting towards internal and external changes. In order to deepen this knowledge another method is to rebuild this system. Replication is done, once we simulate systems by building representative models of the original. Once a representative model is established, controlling the parameters of the model allows the retrieval of knowledge regarding the system's behaviour towards changes. This knowledge can be used to optimise the system settings towards external influences and also to state "what-if" questions by experimenting with possible scenarios. In general this methodology is derived from the formal science, but in order to establish a sound guidance for simulation projects, Law & Kelton (2000) and Banks et al. (2005) provide a procedure for the systematic building of simulation models, beginning with the phase of problem definition up to the implementation of the results.

Adopted Research Methodology

In practice, the established procedure for simulation modelling is not as stringent or linear as is proposed by the authors Banks et al. (2005) and Law & Kelton (2000). In order to apply this research in practice, the research methodology is grouped into five major phases:

- *Phase 1*: Problem Definition;
- *Phase 2*: Data Collection and Model Conceptualisation;
- *Phase 3*: Modelling and Experimental Design;
- *Phase 4*: Analysis;
- *Phase 5*: Optimisation.

Within these phases, the procedural stages are grouped into quantitative and qualitative approaches. The flow of the applied research methodologies, and their

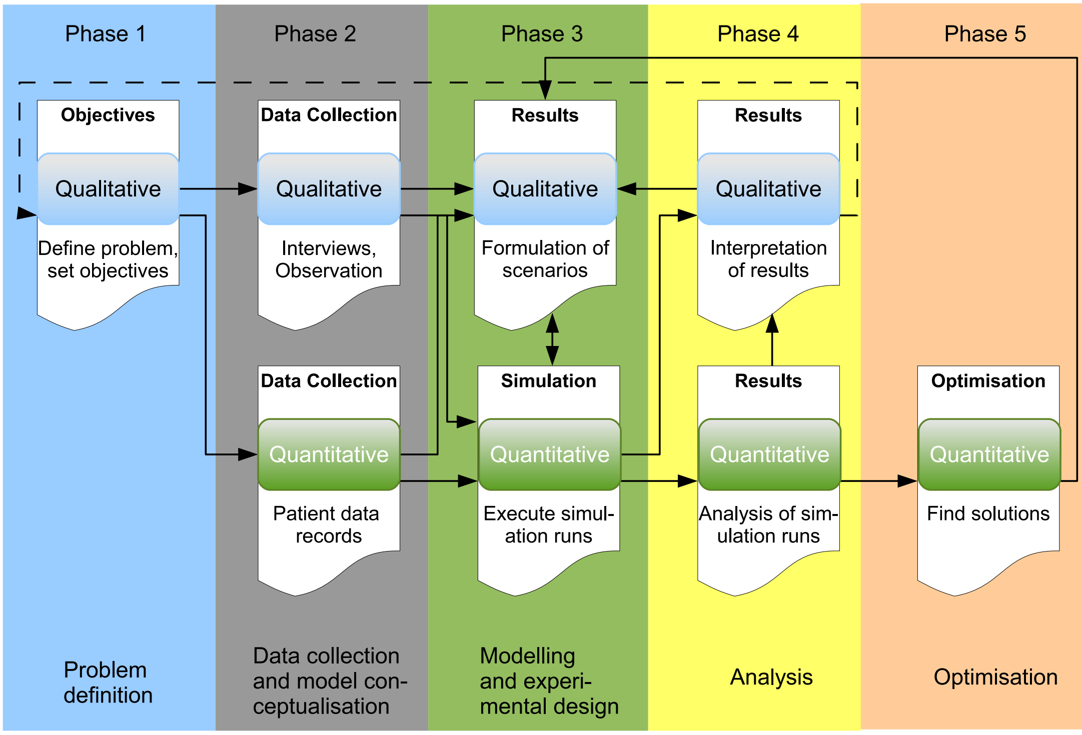


Figure 3.1: Research methodology to guide through the research.

stages within the phases are illustrated in Figure 3.1. This approach guides the research through all main phases and allocates the appropriate research methodologies for each step.

Phase 1: Problem Definition The initial phase is the *Problem Definition* where the objectives are discussed and set with the stakeholders of the project. As this stage is designed to negotiate and identify the scope of the project, and to interview the stakeholders about the contents of the deliveries, this particular stage is qualitative based. Interview techniques are accessed to identify the first estimates about the later stages of the project. Based on the outcome of the *Problem Definition* phase, the *Data Collection* is triggered and initialised in the *Data Collection and Model Conceptualisation* phase. The phase of the *Problem Definition* is based on experience taken from previous simulation modelling projects. The experienced modeller can estimate the scope of the project and the required amount of data. The inexperienced modeller however has to access and consider successive steps before a negotiation and a sound estimate regarding the scope of the project can be made.

Phase 2: Data Collection and Model Conceptualisation At this stage are both research methodologies, quantitative and qualitative are accessed. In order to retrieve information about the flow of the patients through the ED, two qualitatives techniques are facilitated. The first technique is the unstructured interviews and the second is the observation. Unstructured interviews are used because the medical staff have limited time and may not be approachable during their work with the patients. The utilisation of the ED is expected to be high, therefore the questions are prepared in advance, but the selected questions are stated depending on the current situation.

To observe the work flow of the facility, there are two sample methods available, the first is the stationary method, where times are taken for specific process steps. As an example of this, the duration of the x-ray is noted on a notepad for specific time periods throughout the day. The second sample method would be to follow certain patients through the system and to note the processes that the patient goes through. Observation and interview are of qualitative nature, whereas the data collection and analysis of patient records is of quantitative nature.

Patient records are stored in the database of the hospital, which can be accessed via a computer engineer. The anonymised data is provided electronically on a CD-ROM and allows sophisticated data analysis without the need to type the data into the computer. The records yield various information regarding each patient, such as arrival time, registration time, triage time and two different treatment times. The time at which the patient leaves the ED is also recorded. In addition to the times, there is also different data stored which describes patient attributes, such as age, sex, the type of the complaint, the medical staff who have seen the patient, and the referral destination. The patient records cover a time range of 22 months. The data is anonymous to guarantee patient data safety.

As the patient data is entered manually, the patient records may contain errors which must be eliminated, or at least well estimated and thus isolated. In order to identify these errors it is worthwhile retrieving redundant information where possible. The several process steps allow the retrieval of redundant information which can be accessed by summing up several steps and comparing them with the total sum. Other redundant information can be used by calculating partial sums and comparing them with the times that are recorded in the patient records. With the use of the redundant information, the data integrity can be checked and validated. On this basis, a filter is created which provides maximum and minimum values for trustworthy data sets. Comparing the remaining data with the filter values, allows the elimination of untrustworthy data sets.

Data processing can be applied with the cleaned data set, where the patient attributes are used for grouping purposes and the duration of the processes is used to calculate statistical distributions which are later used for the simulation model. Patient arrival data is used in order to verify the simulation results with the hospital patient data records.

The information retrieved in the data collection phase needs to be recorded and arranged in an obvious manner. The quantitative data is arranged in the following way: The patient data is grouped and arranged in frequency tables and graphs. The durations are summed up by their statistical attributes, such as average, standard deviation, minimum and maximum values, median, first and third quartile and variance of the values. Hypothesis tests for the statistical distributions identify key values for statistical estimates.

The qualitative data is arranged in conceptual models, such as flow charts and adjusted IDEF0 models, which consider the use and facilitation of resources. See Figure 3.3 as an example of chest pain patients in an IDEF0 model and Figure

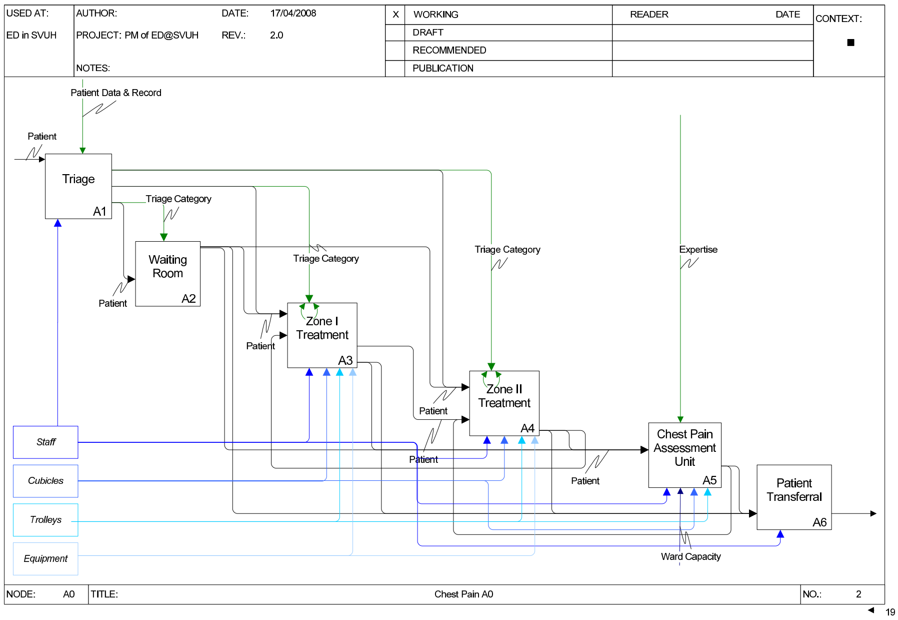


Figure 3.2: 1st level IDEF0-hierarchy slide to represent the overall chest pain process.

3.4 as an example of a flow chart. The IDEF0 (Integration Definition for Function Modelling) is the functional modelling standard which is described in the manual issued by the National Institute of Standards and Technology (2010). This manual provides 10 different modelling techniques. An explanation of the applied IDEF0 modelling technique is provided in the Appendix E.1 on Page 342.

Due to the vast possibilities to incorporate hierarchy levels, a high detail level of modelling can be achieved in a structured way. However, due to the complex details, the conceptual model as a whole, is increasingly difficult to read and to understand. In our example, the booklet contains 209 pages, of which 84 pages are IDEF0 charts. These can be retrieved in full from the Appendix E.2 starting from Page 345 to 451.

The flow graph and the IDEF0 model are combined in an overall conceptual model in a twofold way: the different flow charts for the most commonly recognised patient complaint groups are assembled in one overall conceptual flow chart model, which will represent the flow of the patients through the ED. The IDEF0 models are plotted with their first three hierarchy levels also compromising the most common

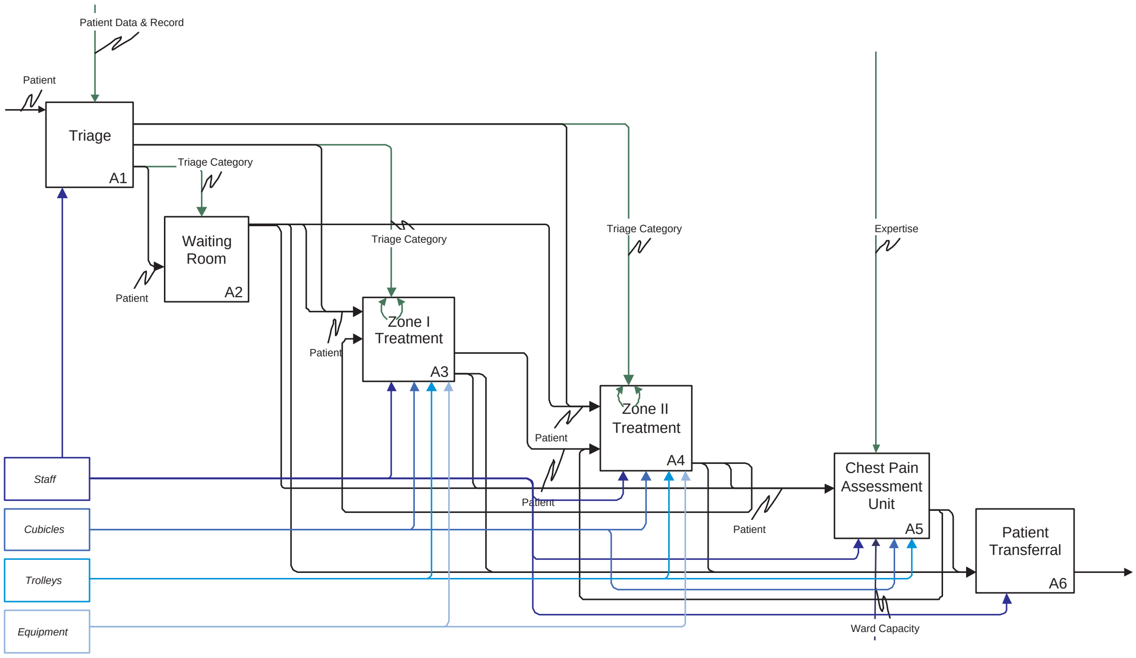


Figure 3.3: IDEF0 example model for chest pain patients under the consideration of resource use.

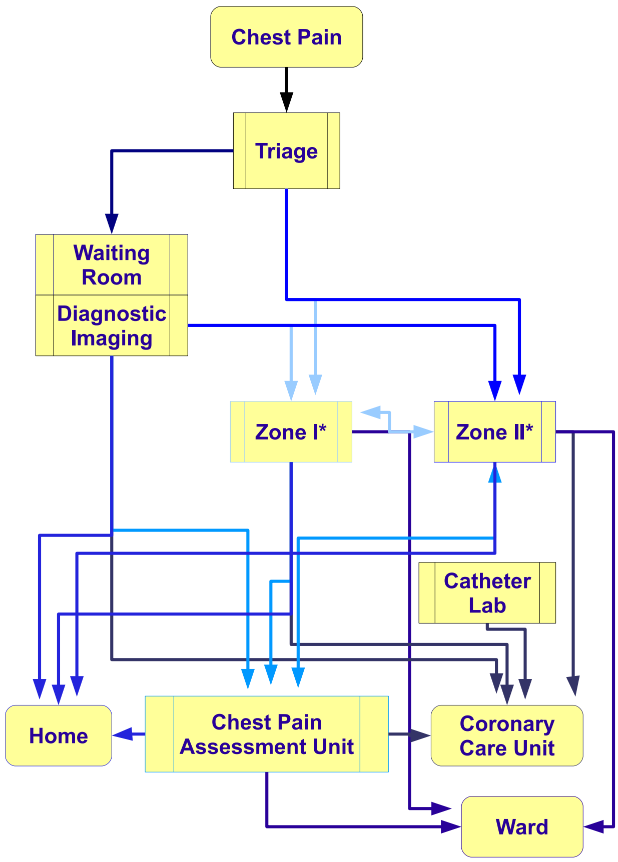


Figure 3.4: Flow Graph example for chest pain patients.

patient complaint groups. These hierarchy level – based IDEF0 models are combined and presented in a booklet. Both the booklet and the overall flow chart are presented to the consultant of the ED as a discussion basis for validation.

Phase 3: Modelling and Experimental Design Once an agreement regarding the validity of a model has been reached, the model can be translated in a simulation model, where both, quantitative and qualitative information is accessed. The translation of the conceptual model is achieved using a simulation software package which contains all required functions and modules. Both models – the booklet containing the IDEF0 model and the overall flow chart – are the basis for the structural layout. The design of the layout is made in two stages, the first stage is the generation of a process flow grid, where the active and the passive pathways are automatically constructed by the algorithm developed for that purpose; the second stage is the final modelling and adjusting of the process flow grid to the structure identified in the booklet and the overall flow chart. The data obtained from the data analysis phase is used to feed the simulation model with the required parameters, such as process times, patient arrival times, available resources and so forth. To complete the model, qualitative and quantitative data are used. These two sources of information yield results, which are also used to formulate scenarios for a deeper analysis of the simulation model. Various validation and verification techniques are a constant companion during the translation of the conceptual model into the quantitative simulation model (Kleijnen 1995). For this purpose, intermediate results are used until the final stage of the model design is reached.

Phase 4: Analysis The built simulation model is then ready for simulation runs, and the results, which are of a quantitative nature can be analysed. Impressions about the observational behaviour of the model are noted and form qualitative statements that can be expressed in statements such as *"'if x is high then y is low"'*. These interpretations, as well as the influence of the statistical analysis, provide feedback for further scenario analysis or even inspire the reformulation of the objectives and motivates to reshape the model.

Phase 5: Optimisation The final phase is *Optimisation*, where an algorithm is identified which is compatible with the model. The input from the resulting analysis delivers an idea of the parameter range, where optimisation may produce valid results. The results of the optimisation are used as scenario parameters and fed into the model. New runs with these parameters are made which must be verified and validated. Once these results are validated, a recommendation can be made regarding the identified parameters.

Recursive Approach

Considering the approach chosen as a research methodology for this investigation, it can be seen that the linear impression of the procedure for simulation modelling, evolves into a circular approach by following the feedback loops into research procedure in cases where the objectives – set in the beginning – are not met. If satisfactory results are not obtainable after several repetitive loops, negotiations with the stakeholders may be essential to reconsider the targets and the objectives of the simulation project.

3.3.3 Research Preparations and Considerations

In general it is important to consider that for the creation of a representative model of any kind, it is essential to prepare the data for each different purpose so that it can later be used in the model construction process. The qualitative data is mainly used for conceptual modelling, whereas process data obtained from the quantitative data is later added to the executable model. The qualitative data is represented in flow charts. To derive the final flow chart, the most common flow chart was chosen.

Differences in the flow chart representation can be explained by the different perspective of the individuals who rate certain tasks as more important than others. With that information at hand the conceptual model is built.

Initialising Research

The conducted field work is targeted at the largest ED in Dublin, where around 45,000 patients are treated each year. This ED treats around 50 different patient cases and experiences a high demand. To initialise the field work a meeting with the management of the St. Vincent University Hospital and a consultant of the ED is planned. Within this meeting the scope of the research project is introduced to the management and the objectives are discussed. The following objectives for the research project are agreed as scenarios that have to be investigated and are referred as practical objectives within this dissertation (see Chapter 6 on page 265):

- Provide key performance indicators (KPI)
- Investigate scenarios on the impact of the introduction of a documentation aid and the employment of an additional doctor;
- Investigate whether the 6 hour target can be achieved under the assumption of an optimised setting;

Within this meeting, the onsite investigation is laid out and planned for the next two weeks and follow up visits are scheduled to discuss the research findings. Meetings for interviewing are arranged to be spontaneous due to the high workload of staff. In order to provide a holistic impression for the model, interviews are planned for all relevant staff types within the ED:

- Medical staff;
    - Consultants;
    - Pharmacists;
    - Physiotherapists;

- Nurses
    - Clinical Nurse Managers;
    - GP Liaison Nurses;
    - Staff Nurses;
- Supportive Staff
    - Porters;
    - Receptionists;
    - Cleaners;

Applied Qualitative Data Mining

In order to retrieve an impression of patient flow within the ED, the medical staff, nurses and supportive staff were interviewed. As the staffs are very busy within the ED, the interview time is kept below 5 minutes for most of the staff. A more thorough interview has been made with 6 doctors who were interviewed for half an hour during their lunch breaks. For the short interviews all staff types are considered and the following questions were asked:

- What patients groups do you treat?
- How long is your average treatment time?
- What is the shortest and longest treatment time in average?
- What have you done recently?
- What are typical patient processes?
- What type of resources is required?

The doctors are asked the same questions but in addition, they are asked to draw a schematic of the main patient flow through the ED. The resulting schematics (Figure 3.5) are taken and merged into an overall process flow map, which resulted in a process map indicating 14 different patient groups. In the second meeting the consultant was asked to verify the findings. The final process flow map which is resulting from the 14 main patient groups is merged in one large map.

In addition to the process flow map, a conceptual model is generated which indicates the utilised resources. This data is based on observations during the first two weeks in the emergency department, where the patients are followed discreetly and their process steps are timed and noted. These process steps are mapped in a high level process mapping technique IDEF0, where also the used resource types are allocated, The observed resource types are classified into staff, medical equipment, trolleys and cubicles. In order to allocate the resources the IDEF0 approach is slightly modified and uses resource pools as mechanisms. An example is provided in Figure 3.6.

Both, the process flow map and the IDEF0 model were facilitated as a conceptual model for the simulation model. The information yielded from the conceptual models is used in order to map the patient flow accordingly. The routing, the sharing of the resources, and the structure is easily transferred to the simulation model. The obtained qualitative data captured process timings and are used to confirm results from the quantitative analysis.

Follow up meetings with the consultants are used in order to check the validity of the resulting conceptual models. If necessary, further hourly visits are made in order to confirm the findings.

Quantitative data

The quantitative data requires more conditioning until it is ready to be used in the later executable model. One reason for this is that statistical tests are made in order to check whether the process or the arrival data is representable in statistical distri-

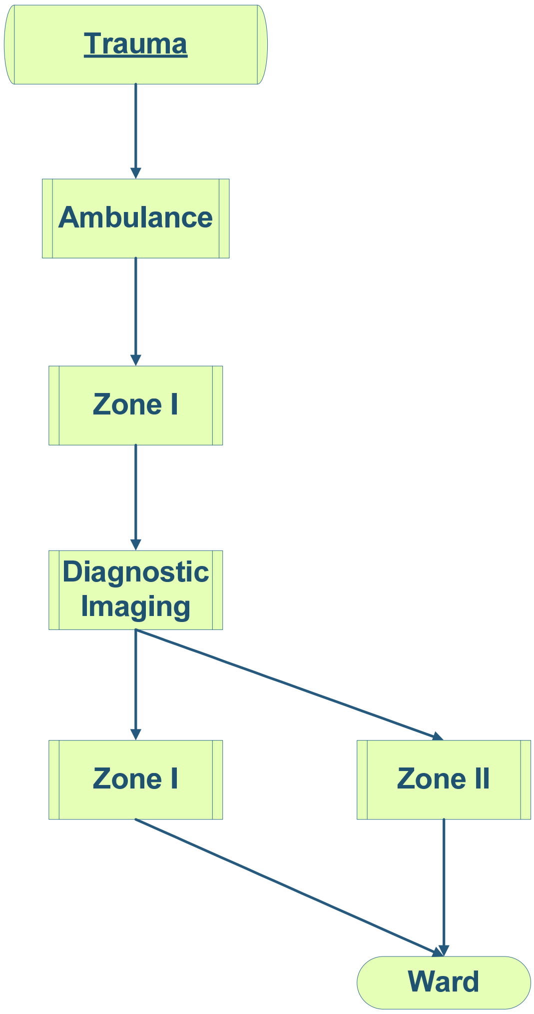


Figure 3.5: Flow chart representing the process flow of trauma patients

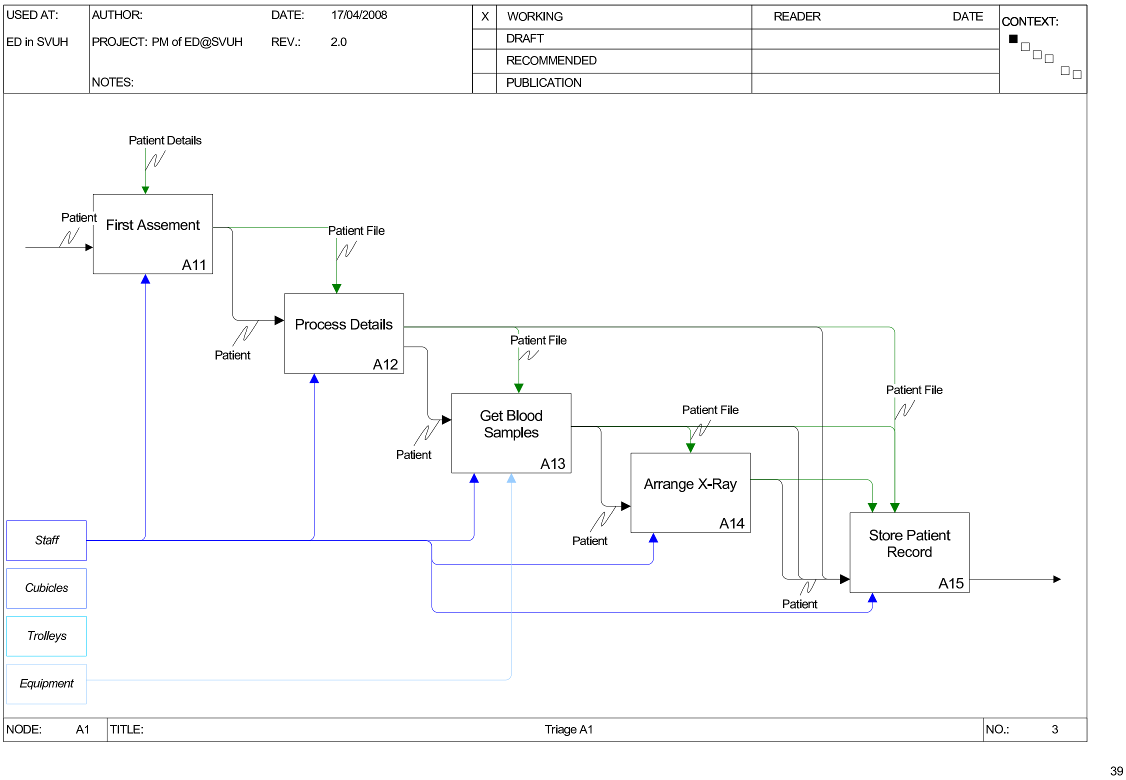


Figure 3.6: IDEF0-Model representing the process to triage abdominal pain patients

butions. Therefore the data must be grouped and evaluated. The data consists of three main categories, the first would be the category of the patient complaint, the second describes which specialty the patient has treated for, and the third categories indicates where the patient is referred to. Within these categories the groups are obtained from their property, for example groups are generated for all patients with the same complaint, such as a headache. Within all of these groups, the statistical attributes like median, standard deviation, variance, median, first and second quartile, location, maximum and minimum values are calculated. Arrival data and process times are also investigated. In order to create a reusable tool, a spreadsheet calculation sub routine, the "Data-Mining-Module", is programmed in Visual Basic which can be reused for any similar presented data set. Additionally, the sub routine delivers frequency tables with their according histograms and also delivers ratios which are required to establish the routing within the model. These ratios indicate where for example the severe patients with certain complaints are diverted within the model. This routing can differ in relation to their severity status. The raw data of each group is also presented which is hence applicable for the arrival times. This is useful for the verification and the validation section in order to demonstrate that the structural model is a valid representation of the system under investigation.

Data Conditioning The hospital under investigation has provided us with drafts from their hospital records which contain relevant anonymous data concerning every patient who has been through the ED within a time span of 20 months. The data, generated with Crystal reports, is arranged in a spreadsheet containing 79,641 lines of patient records. Each line represents the following patient attributes: the patient identification number, the registration date, age and sex of the patient, the patient complaint, the specialist who has seen the patient, and the referral status of the patient. For the data commencing from the twelfth month, the triage classification is included which indicates the status of severity of the patient. The different process stages are recorded and indicate at what time the patient has seen the triage nurse as well as at what time the treatment commenced. Following this, a decision is made by the ED if the patient should be admitted to the hospital and at what time the patient left the ED. These patient records are directly entered by the treatment staff, while they document the patient cases on their computers. Additional redundant information is provided which displays the durations of time spent by the patient since the registration: the duration of waiting to be seen for triage, the time spent in the waiting room including the triage wait, the duration until the treatment commenced, the duration until an admission decision has been made and the total time spent within the ED. The values of the durations differ to those entered by the treatment staff, which were used to identify them as outliers.

The quality of the data is questionable due to several reasons: first, the data is entered manually and, as observations show, a considerable time later than the patient was actually seen. This indicated that the staff member either lacked a good memory or made a good guess of the accurate time when the patient was seen. Secondly, the time and date settings of the computers were sometimes not set correctly which resulted in negative time durations, and thirdly, approximately 55% of timing entries were left blank as were 27% of group identifications such as complaints, specialty or referrals. For example, the specialty was only entered for around 30% of potential fields.

One cause for the state of data may be the stressful working conditions which may have been observed during the observation phases. However, the hospital records provided valuable information which had to be separated from the outliers included in the data set. This can be achieved by making use of the redundant information provided within the data fields that were used to measure the durations. In order to filter the trustworthy datasets, the durations of the each patient has been obtained. The sum of these durations has been compared with the provided durations. In cases where the durations were equal or within an error range of 15% then the particular data set is considered to be trustworthy and considered for further investigation. Those records failing this test were discarded. After this test 15,000 trustworthy data sets remained. To facilitate the remaining data, the maximum and minimum values for each group are obtained in order to eliminate the outliers within the remaining data.

Data Grouping The patient data can be split up into two categories, the first is the timing data, which indicates the certain timestamps, and the descriptional data, which describes the patient and his / her pathway through the ED. The timing data is used to retrieve statistical distributions and to provide the essential process data. The descriptive data is used in order to aggregate groups, such as complaint groups, specialty groups, and referral groups. The complaint group for the data from 2008 yields 49 different groups of which the most frequent has is the "Limb Problems" group with 7510 cases, second most frequent is the "Unwell Adult" with 4354 cases, while the fewest cases is the "Irritable Child" with 2 cases. The specialty groups reflect the certain specialties which treated a patient of which there are 18. The referral group indicates the referral possibilities of which there are 26 different entries in the table, which are hence cumulative into 5 main groups, as the Ambulatory Day Care Centre (ADCC) indicates an inpatient clinic within the hospital (see Appendix 7.5 for further details). All of the possible patient groups are used in order to retrieve specific process times for each complaint, specialty or referral. These process times are invaluable information for the simulation model, because it allows tests for statistical distributions which are used as process times for the random generator within the simulation model. In addition to the process times, the age, sex, and arrival pattern is obtained and displayed in histograms or pie charts. The grouped patient data is retrievable from the appendix provided by the DVD.

Processing Data In order to model healthcare facilities, several parameters have to be investigated and taken into account: process times for treatment with their according time distribution for each patient and treatment group, patient arrival distribution, routing of the patient within the healthcare facility, as well as the staff allocation. These parameters can be obtained by the hospital records, staff interviews or by observations. Due to this list of required parameters, it is apparently obvious that DES is not the fastest procedure in order to retrieve forecasts. However, obtaining patient arrival and generating estimations is very relevant. These estimations are represented by distributions which represent a common pattern which allows reproducing the patient arrival and can be used for forecasting purposes. As an arrival pattern, the Poisson distribution is commonly identified by investigating the hospital records. For example (Bowers & Mould 2004) investigate the arrival pattern of an orthopaedic trauma centre which resulted in a stochastic pattern, where the Poisson distribution showed to produce the best fit. This distribution is varied in their means to adjust to arriving hour, day and season which is hence applied for the simulation model. Another example of fitting distribution to arrival data can be obtained by de Bruin et al. (2007), where the frequencies – according to the grouped arrival minute category – display an exponential distribution, which is later shown to be Poisson.

To retrieve the patient process time, durations are calculated from the data set: the first process is the wait for triage obtained from the difference and the time taken at the triage; the second process is the wait for treatment, which is the difference between the treatment commencement and the triage time. These two processes combined describe the wait in the waiting room. The treatment time is described in the "treatment time 1" and the "treatment time 2" which is the difference between the start of the treatment and the decision to admit and the difference to the referral time stamp respectively. The total time spent describes the length of stay within the ED.

In order to acquire the relevant process data, general descriptive statistic measurements are derived such as average, minimum-, maximum value, standard deviation, variance, median, first- and third quartile, and the interquartile range. All together there are three different average values available, first the common average, second the median, and thirdly the location which is the maximum value derived from a histogram which counts the frequency of time occurrences. The median is an alternative representation to the average value, which has the advantage of being robust against outliers due to its ranking. Another indicator, named as location (here), is facilitated and is a parameter to describe exponential distributions. The location is retrieved from the frequency histogram of the process times: the value marking the maximum is the one indicating the location at which time duration interval is most likely to appear. The location can therefore be directly used for skewed statistical distributions such as log-normal.

Patient Arrival Data The interarrival data is of special interest because it displays the time delay between two patient arrivals. This data is required for the simulation application in order to replicate the patient arrival patterns. To do so, there are two possibilities: either to use the current data, obtained from the hospital records, or to use estimations that are representative distributions from the hospital records. For the first possibilities the statistical integrity must be considered. In order to test the statistical integrity, the arrival times are obtained from 660 patients. These times are assumed have be arrived on the same day, but on their specific time as they arrived. The frequency pattern of arrival is then compared with the average daily arrival pattern. The samples show that with a confidence level of 99%, the confidence interval of 5% could be maintained at each time (hour). For that reason it could be assumed that the arrival times are a valid representation and errors are not widely spread within the data. However, when sorting the hospital data for interarrival durations, it can be seen that 5 patient sets had negative time durations; those data sets were not taken into consideration.

In order to test the patient records for statistical distributions, the analysis is carried out identically to the test of the process times. The difference is that here the time between the arrivals of patients is obtained and grouped into time slots. The frequency of the occurring time slot is then accumulated and represented in a histogram. The histograms drawn from the hospital data analysis (see example for chest pain patients in Figure 3.7) appear as if it would be a lognormal or Poisson distribution. However, having tested these distributions with actual distributions by applying the program Stat::Fit, it can be seen that most of the patient distributions are rejected and only a few actually fit into a common statistical distribution.

Another important indicator for the patient arrival is the patient arrival rate, which indicates the number of arrivals per time unit. This rate is accumulated and treated equivalent to the process times, in order to test the data for statistical distributions. These statistical distributions can be used in order to generate a generalised

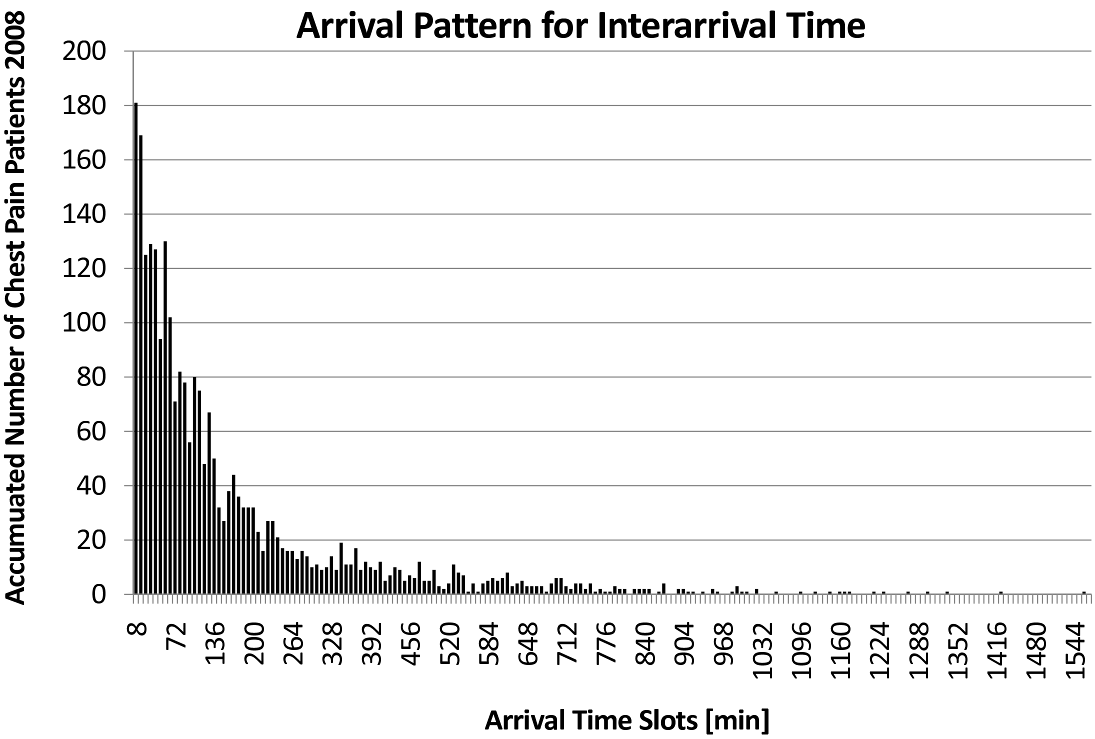


Figure 3.7: Accumulated chest pain patient arrival over the timespan of ten months displayed in a frequency histogram.

patient arrival model for future representations of the simulation model. It is also possible to apply the recent arrival rate, in case a repetition of the certain year is desired. This is highly recommendable for verification and validation purposes.

Routing Information The routing information describes the journey that a patient follows during his / her visit to the ED. The accuracy of the hospital record is not very high; however relevant information is still retrievable by considering the uncertainty with either retrieving redundant data or to include the variance in the calculation. To retrieve the routing data, timings are combined with the text field, which describes the location of the time stamp taken. The specialties are dedicated to certain units within the ED, therefore it can be specified to which unit a patient went, when he / she was, by whom and for how long. Additionally, it can be seen where the patient has been referred to. This information is applicable to all complaints groups and gives an indicator on the routing by obtaining the recent percentage on the possible routes. This routing information is transferred to the simulation model where the patients are distributed accordingly.

At the end of this stage, the data should be arranged in a manner which allows for a conceptual model can be built. That implies that the quantitative data must be grouped in such a way that the statistical distributions can represent the processes, and that the qualitative data can be used for the generation of process flow diagrams. Additional qualitative data may yield information that can be used for statistical evaluation and vice versa: the quantitative data can unfold process information which may be valuable for the routing of the items through the system. Having the prepared data at hand, this allows for the completion of a conceptual model, which is an abstract description or schematic for the latter simulation model. The modeller has a wide choice of conceptual modelling techniques available, such as process flow diagrams, business process modelling notations (BPMN), Petri Nets and so forth (Robinson 2007*a*, Robinson 2007*b*, Ryan & Heavey 2006). It is important at this stage that the conceptual model is generalisable and understandable for non experts as this will be used for discussion purposes (Robinson et al. 2004).

The conceptual model is used for two purposes: first it is a guidance for the latter actual simulation model, which contains and considers a higher degree of details, and second it is used as a communication platform in order to validate the model with experts working within the real system. Once the conceptual model can be used for communication and validation, the step indicating a decision point is reached, where the question is stated whether the "Conceptual model is valid?". If the experts express doubts or concerns, the modeller must go back to the beginning of the second step and refine or alter the model.

In case where the experts agree on the credibility and validity of the model, the construction of simulation model and verification begins. The simulation model can either be the programming of code, or modelling with the use of a simulation software package, which provides the modeller with tools that are typical and essential for such a modelling technique. The procedure is often referred to as model translation, due to the fact that it describes the transformation of the abstract conceptual model into a more detailed, complex and executable simulation model.

3.4 Discussion

The procedure of simulation modelling is often discussed for its wider application and even as its own research methodology. In order to understand the motives for this idea, this discussion will clarify the intentions of the main authors representing this thesis. These two authors – Eldabi, Irani, Paul & Love and Axelrod – who link the quantitative and the qualitative research methodology with the DES modelling procedure are therefore discussed here. This ongoing discussion is not practised as a methodology in itself, and instead is used to ascertain the strengths of the simulation approach.

DES is often regarded as a quantitative research tool, as tangible information can easily be considered and integrated into the modelling phases. Tangible information is aggregately linked to determinable facts which influence the outcome of the model. Eldabi, Irani, Paul & Love (2002) claim that in addition to tangible information, intangible information can be considered within DES modelling. Intangible information is not clearly defined by the authors but is related to the structural information of the model itself. It would be difficult to establish where this intangible information would be inserted in the modelling procedure as a discrete point, but the overall procedure allows for the retrieval of intangible information with the conjunction of the feedback from the stakeholders – that would be possible to incorporate the feedback either during the verification or the validation phase.

It is also emphasised by certain authors (Eldabi, Irani, Paul & Love 2002) that even ill-defined research objectives are determinable by applying the modelling procedure as it is described above, but at the phase during which results are analysed, it is recommended to use theory discovery in order to narrow down the research objective to a more precise problem definition.

In addition to this discussion the authors deliver an overview in the form of a table, via which they suggest how DES could overcome the weaknesses of the quantitative or the qualitative research methodology. Having shown that the DES modelling procedure would be applicable as a qualitative and quantitative research approach, they also conclude that the DES modelling procedure provides a research process which is developed on a sound framework which not only provides a deeper understanding of the by-products of scientific enquiry but also of the process itself (Eldabi, Irani, Paul & Love 2002).

Axelrod (1997), on the other hand, takes a different approach as to why DES is applicable either as quantitative or even as qualitative research methodology. He highlights the use of DES as a reasoning technique by referencing DES to induction and deduction. Inductive reasoning – also referred to as induction reasoning – attempts to draw conclusions from observations. These observations can be empirically recorded, allowing for the discovery of patterns. Inductive reasoning is a common stage in the simulation modelling procedure, where observations are obtained in order to describe the model. Deduction specifies a set of premises which are used in order to draw conclusions. Deductive arguments are rated by validity and soundness and should not be rated as true or false. Axelrod claims that simulation modelling uses a set of explicit assumptions as in deduction, but instead of proving theorems, simulation models produce data which can then be investigated inductively. Hence, this induction differs to the typical inductions as the data originates from a set of rules and is not obtained from observations of the real world. With regards to this argumentation, Axelrod highlights that simulation modelling is a tool for tracing intuitions (Axelrod 1997).

The discussions provide a solid backup for the simulation modelling approach as a potential research methodology either in quantitative research or even in qualitative research. However, having a theoretical support is a sound basis for research put in practice, but acceptance for modelling techniques is also measured on the applicability of the actual system under investigation. DES allows complex modelling, but in some cases alternative approaches should be evaluated which allow the retrieval of the desired findings with less effort. However, knowing that DES is applicable as a comprehensive research methodology, is valuable, but one should bear in mind the costs which accumulate whilst deciding on this solution finding technique. Cooper et al. (2007) support this consideration by referring to the acceptance of modelling techniques which are based on the model 'error', model appropriateness, dimensionality and ease and speed of model development. This statement is a nice example that even if in theory everything appears to be solid and sound, in practice it shows, that improvement is still necessary.

Chapter 4

Decision Support System for Emergency Departments

In this chapter a novel framework is presented which details the development of a concept named as Multiple Participant Pathway Modelling (MPPM) which can be applied in certain servicescape environments such as in healthcare or tourism. Within this concept, the common notion of focusing on one item travelling through a system is supplemented by additional pathways of the resources or production units. In servicescape for example, costumers describe one pathway, while service providers have their own work flow, which is connected with the primary pathway of the customer. The work flow should thus be regarded as the secondary pathway. In order to be more precise with the terminology, the primary pathway is regarded and referenced as a passive pathway, because the items / customers allocated to the primary pathway, "experience" the procedure that is applied by the resources (i.e. assembly line) or service providers (i.e. call centres). The secondary pathway is addressed as an active pathway, because the resources or service providers interact "actively" with the item / customer. Within this concept, multiple participants can be associated within one comprehensive holistic network, where active and passive pathways are distinguished.

This chapter will present a description of how the modeller successfully applies Flexible Resource Allocation (FRA) to his model, and how the essential modules which enable FRA are constructed. In order to apply FRA, initial steps must be considered such as explaining the preparation of the project and system considerations. This initial step determine whether FRA is a suitable method for the modeller to represent the system adequately. A discussion regarding the requirements of the simulation packages is also provided. Hence the constructions and their purposes are explained in detail. The logic within the module and the necessary embedded logic are also described. Consequences of the data retrieval and interpretation of the simulation data is provided in Section 5.5 on Page 241. In addition to this framework, evidence proving the workability of the concept is provided by applying this framework to the ED of the St. Vincent University Hospital located in Dublin (Ireland).

4.1 Flexible Resource Allocation Framework

In healthcare and especially in hospitals, patients are described by their primary pathway, while the resources needed for treatment are the medical staff, who follow their demand driven work plan. The medical staff must be flexible and are allocated to the patients that require treatment. In this framework the "interlinked pathway modelling of limited connected resources" is demonstrated and allows the application of this Flexible Resource Allocation (FRA), which in turn allows mapping of multiple pathways.

FRA can be observed when several different processes share the same resources. The resulting effects such as process blocking, deadlocks, or shortages of supply, appear dynamic and complex to the outside observer and sometimes are even confusing. Especially in systems where a high utilisation of resources can be observed, these effects have a significant impact on the work flow. Once a representative model is required of such a dynamic system, the modeller must consider these effects by modelling FRA. Shared resources among several processes are very common in the servicescape; therefore once the amount of shared resources increases the model tends to become more complex. However, complexity is not necessarily complicated; it should instead be considered as the connectivity of several states or events. This connectivity of resources requires a high degree of coordination. The guideline provided within this chapter simplifies the complicated modelling and coordinates the modelling procedure. The modeller is therefore able to complete the complex models faster than would usually be required.

Integrating FRA components into a simulation model does not only involve a modification of the simulation modelling, but also has an impact on various other steps within the simulation modelling framework, such as impact on the data retrieval, conceptual modelling, verification and validation as well as optimisation. Within this section the reader will continue on the instruction with the assumption of an ideal setting, and what data will be required, in order to model FRA in a complete way. The ideal setting assumes that all the required data is available.

4.1.1 Multiple Participant Pathway Modelling

The purpose of this section is to deliver a general insight into and an understanding of, the application of FRA within Discrete Event Simulation (DES). The authors' ambition is to enable a comprehension, which covers the applicability, the essential preparation, and a detailed construction guideline. This guideline should be detailed enough to be implemented, by any modeller with any simulation package or programming language. It must be considered that modelling principles and structures are delivered which helps to create the code / model which considers FRA. Those interessted in application of the proposed modell find the required structure and guideline for coding and implementation into a simulation package or programming language within this dissertation.

A characteristic of FRA is the sharing of resources among several processes. This can be observed in servicescape, where the resources are either scarce or limited in availability. Consequences of the processes can be described as follows: once a resource is not available to a process, the process is on hold or better said it is idle until the resource is available. Queues build up and cause blocks due to the missing resource. This additional idle time is a waste of valuable resources, because the resource cannot be used for its original intention. Resources here can be human resources, equipment or other resources that are essential for the completion of a process. In working environments with high demand resulting in high utilisation of resources, the blocking of resources causes significant delays for the processes. An additional delay can be caused by lengthy queues, where additional capacity is demanded by customers.

As an example, a hypothetical scenario is assumed: a nurse in an ED is responsible for several patients at several stages within their journey through the ED. As she cannot be at two places at the same time, the doctor who requires her assistance must wait for her arrival. Meanwhile, patients are queuing up to see a doctor and are becoming inpatient. Due to this, the patients begin complaining and asking another staff member for an explanation. This staff member cannot proceed with his / her original task whilst occupied with the unsatisfied patients. The impact on the FRA becomes higher once the demand is high. This cascading effect is one cause for non linearity within the system (see utilisation investigations in section 4.3 on page 187). Within this small example it becomes obvious how the FRA of the nurse is affecting several other processes: delay of the doctor, longer queues and a distracted staff member. In order to model these dynamics within a high demand and utilised system it is important to consider FRA within the model.

Applying FRA is not only done by generating the correct code or model, there are several aspects integrated which must be considered: *first is the investigation* of the system under investigation and its shared resources. The resources should be carefully observed and traced. Obtaining this information can sometimes only be done by on site observation, unless sophisticated object tracing technology, such as RFID, is installed. In order to see and display its distribution within the system, the modeller may wish to access tools from the conceptual modelling. A modified IDEF0 (National Institute of Standards and Technology 2010) approach can be used in order to allocate the resources throughout the hierarchy of the model, described in section 4.1.2. *Second, modelling,* the shared resources might describe a process pathway on its own. For example, our field work investigated nurses, and on their way to see the patients they were required to document their treatment which is an additional process within the shared route. If the ED were modelled without FRA, it is likely that this process detail would have been missed out, or even have been too complicated for consideration. *Third, interpretation of the simulation results.* The modeller must be aware of the objectives while interpreting the data. "Nothing is less productive than finding the right solution to the wrong problem" (Musselman 1994, p. 88). This is a direct appeal not to lose focus. The modeller can easily be distracted by the huge range of problems which are inherited in a complex system. *Fourth, the presentation.* As there are several processes connected with each other, the modeller may wish to consider which results are applicable as a key performance indicator, and which results best summarise the solution to the problem. In case where the modeller uses animation to display the results, care should be taken as to the amount of processes to be displayed. Indeed, too much movement can confuse the observer easily and disguise from the actual solution of the problem. It is now apparent that coding / or translating the FRA principles is just one part of the task. The impact on the framework for simulation modelling will be displayed in more detail in Section 5.5, which results in an adapted simulation framework for FRA.

Within this instruction set, simulation procedures are considered which are not directly involved in simulation modelling, but are an essential preparation and also required for post processing. The instructions on simulation modelling are provided in section 4.1.3 which delivers a guideline on modelling. Previous steps such as data retrieval and conceptual modelling, as well as the succeeding steps like verification and validation are considered in this section. As simulation is a comprehensive analysis instrument of a system, the modeller will have to consider the following provided recommendations. The recommendations given within this sub chapter assume that data is completely available and flawless. For the quantitative data this would result in all steps being recorded in a correct way, with no recording of erroneous data. The qualitative data on the interview side would show, that everybody is honest regarding their workload and times, and that everybody is committed to providing any requested data. The qualitative observational data is recoded correctly by omnipresent observers. These assumptions regarding the data are highly hypothetical and unrealistic, but for the instructions provided on the FRA concept it is essential to describe the ideal world. Limitations are discussed (see Section **??** on page **??**) while the consequences of FRA on the whole simulation framework are considered within Section.

4.1.2 Considerations for the Analysis of the System under Investigation

There is a common appeal from simulation experts to keep the simulation model as simple as possible (Axelrod 1997, Musselman 1992). However, once dependencies of resources and their impacts are investigated, the modeller will most likely have no other option than to increase the degree of complexity. Hereby it should be noted, that the complexity can be increased without making the overall system complicated, as long as the certain structure is coordinated and maintained. The FRA framework, illustrated here, provides guidance for that modelling. However, before the modeller gets started with the modelling, he / she should take the following considerations into account. The system under investigation itself should show certain features. Work flow arrangements, where processes share the same resources, are a potential area for FRA application. Here the demanded resource can cause shortage of supply which sets the other process on hold until the resource becomes available for the other process. The more shared resources there are among the work flow setting, the more likely the occurrence of unexpected shortages of supply. This phenomena is particularly crucial in work flow arrangements where there is a high demand, which results in high utilisation of resources. This high demand requires a quick response system in order to deliver the requested product to the customer. This requires a smooth and uninterrupted work flow – it is therefore of special interest to trace the flow of the resources and to ensure their availability.

Once a system does not show signs of shared resources within its processes, the modeller, for the sake of simplicity, should consider the common simulation modelling approach as discussed in chapter 3. The necessary details can be added once it becomes essential for achieving the objective.

The available anonymised data for modelling can be separated into two main categories: first is the qualitative data, which can be retrieved by interviewing staff, and carrying out observations, while the second is based on recorded data, such as it is stored in hospital records. As total completeness is assumed, information on the patient and on the healthcare facility is redundant. Interviews of staff and patients reveal the process flow of the system and provide the modeller with an idea of the setup of the system. Conceptual modelling techniques can be facilitated in order to map the verbal information which can be used for discussion and as a basis for the actual simulation modelling. Additional interview information can be gathered about process times, which can be collected for further analysis. Observations allow a verification of the understanding gained by interviews.

Quantitative data is retrieved from hospital records which yield valuable information regarding patient arrival times as well as the process times of the patient. This data is stored in a structured manner, such as on a database. This data is commonly distributed over several databases, which must be locatable as well as accessible. Within these databases, the data can be queried by a specific query language. UML diagrams can be facilitated in order to ease this query, so that all requested data is summarised in a report. The modeller is well advised to structure the report in the same way that the simulation model results would report their results. This eases the comparison of the model data with the real data, which accelerates the verification and validation of the model. Automated tools for the data collection and data processing allow shortening the time investigative task for the modeller (Bengtsson et al. 2009).

However, as the data in the hospital information systems is not stored in the format that is required for simulation modelling, further data conditioning is necessary. This conditioning groups the data according to the correct processes and derives the underlying statistical distributions. This step is essential in order to replicate the randomness of the process. Patient arrival data also requires categorisation into the groups diverted to the according processes. Ideally, this information is already retrieved by the qualitative investigation, where now the information on the diversion rate and destination is derived from the quantitative data. Higher precision of the underlying data can be gained by acquiring several process statistics, such as patient process and staff process times. For example, the patients' process includes the wait for staff, the time of staff can be subtracted from the patient process, which reflects the waiting time. This waiting time is usually unseen if we only consider the patient process which is represented within the cubicle.

Even though the information itself which is required to build a simulation model can be expected to be available, the problem in real life, however, is to collect and retrieve it. Often it is not available at all, due to the fact that particular records of interest are not kept, or the information available contains errors due to typos, or personal misjudgements. Data retrieval is a very demanding task, during which the modeller must retrieve as much redundant data as possible, in order to get a correct impression of the system under investigation.

Data availability from the simulation model is subject to the applied simulation software package. Usually the modeller has all the freedom and influence required to retrieve all the necessary data. As mentioned above the modeller is well advised to structure the data similarly to how it has been retrieved in the original data set of the real data. This allows the modeller to apply the same evaluation techniques as were previously applied with the original data. Comparisons between the simulation results and the original results can directly be applied.

In case the simulation model is simulated with an empty model, a warm up period must be considered, which populates the model (Yeh & Lin 2007). A steady state describes the state of the model where queues have converged over time to a certain number, where an observable fluctuation is reached. This steady state can be obtained once the queues have reached an observable average, around which the current number oscillates.

The output results depend on the type of simulation, such as terminating simulation, or nonterminating simulation. Nonterminating simulations are not triggered by an event which sends a stopping signal when a certain condition is met, or a timestamp is reached. In general, simulation results are commonly a product of multiple randomly distributed processes. A high variation in the results is not uncommon. Replications of the simulation run provide sound data integrated by retrieving averages and the standard deviation. In order to retrieve the correct sample size, for a certain confidence level, the following formula should be considered:

$$n \cong z^2_{1-\frac{\alpha}{2}} \frac{s^2}{h^2} \tag{4.1}$$

where n represents the sample size, α the confidence level, z resulting factor based on the statistical distribution, s is the standard deviation and h the confidence interval. This confidence interval is also commonly applied in order to describe the error range in which a resulting value may appear. In simulation modelling, where the variance of simulation results can increase, it is essential for the modeller to run sufficient repetitions and also to identify the error range.

Consideration of Objective

Modelling FRA should not be practised as an end in itself; the modeller should check whether this method is truly applicable for the system under investigation. A common domain where FRA is applicable is the servicescape, where work is shared among reserve pool employees. Here, the processes share the same resources and in addition the allocation is demand driven. Therefore, it is difficult to predict in advance, where the employee will be assigned next. Healthcare for example is such a domain, where the FRA is a common feature among nurses. Particularly in facilities where high demand periods are likely, reserve pool nurses are hired in order to even demand peaks. A good example would be the ED where high demand periods are difficult to predict and several EDs within the same catchment area share a common reserve pool of nurses. The nurses are available on call and can be facilitated very quickly. This is a reserve pool which is located outside of the concerned facility, but there are also reserve pools within the facility where the employees are not specifically assigned to one unit explicitly.

An application domain is demanding for FRA when:

- Processes are sharing the same resources, e.g. pooled nurses available on demand;
- Resources are located in a demand driven manner;
- The system is experiencing high demand;
- Unexpected queues are appearing which cannot be explained in any other way;
- Previous simulation or any other analysis did not / or would not deliver satisfying results;
- Multiple flows of different items / participant types are present.

The above stated conditions can be regarded as a check list for the modeller, which should be considered before modelling with a view to tracing and identify the unexplained blockings within a system. The list above can be checked during the first initial observational visits during the problem formulation phase; this is included in the preparation of the modelling process. Hence thorough preparation is the best guarantee for success (Musselman 1998).

For the sake of simplicity with regards to the project, the modeller should consider these bullet points, even though the framework provides a good guidance and will simplify the modelling procedure of FRA. However, a certain degree of difficulty is inherited within this procedure, which should not be ignored.

Evaluation of Domain

For the modelling of FRA, the modeller should consider that the aforementioned requirements with regards to the simulation software are met. As these are very general in description, its application should be feasible to many simulation software packages which are based on object oriented programming language. Hence focusing on the construction of such FRA models, some considerations should be addressed in the preface, such as the availability of statistical analysis regarding the retrieved data. Another consideration is whether tools are available for support within the simulation package. If not, are these applications available from a different distributor? Clarifying this in advance is beneficial as the modeller may wish to create an appropriate interface for the data import and export.

Another consideration would be what kind of programming interface to use. Usually a vast amount of programming is not required in order to construct FRA, but certain adjustments must be made. For these adjustments the modeller should familiarise him or herself with the programming language and how a mechanism such as inheritance can be facilitated in order to create multiple replicas of certain template modules.

Many simulation applications provide predefined functions in a block style that can be easily located by using the click and point mechanisms. It can be presumed that the instructions using verbal descriptions supported by BPMN and Nassi-Schneiderman- diagrams (also known as Structogram) (Nassi & Shneiderman 1973) are a valid way of communicating this idea. Replicas can easily be developed by following these provided instructions.

Data Evaluation

Once the objectives are set, it is important to evaluate the data availability. A good model is worthless without a good and sound data analysis (Bradley et al. 1999, Ceglowski et al. 2007). A work flow system can be described by quantitative data, such as process times, certain timestamps taken, arrival, and delivery times. The quantitative number of treated or seen patients is also necessary. In healthcare systems, patient times which are documented in the Hospital Information System (HIS) are usually patient related. These records can be obtained from the HIS and be facilitated for quantitative analysis regarding the patients journey throughout the facility under investigation. Here it should be noted that the detail level of the data must be adjusted to the desired objective. For example, if the objective is to identify the mean patient throughput time, it may well be unnecessary to measure the time it takes to apply an injection or infusion.

Another data category would be the resources which are in use and available within the system. Here, deciding which resources should be considered for investigation is again dependent on the objective. Resources are staff (human resources), equipment, and infrastructure such as used buildings. These resources are limited, countable and have a certain value, usually expressed as cost per time unit. The data obtained here is useful for optimisation purposes, as it can be used as a constraint for the objective function. The resources are bound with special properties, for example, maintenance circle times for medical equipment, or shift and break times for staff. These properties involve other frequent repetitive processes which can be considered in separate process flows within the simulation model.

Human resources like employees are characterised by their qualification level, which also defines the task they are able or allowed to do. Being bound to this qualification level as a job description is a rather wage structure, because the definitions of certain roles may not be in keeping with the realities of the job. Unlike equipment, which is available 24 hours a day, working staff members require regenerative pauses and are limited to their shift duration. A simulation model designed to model shift time of staff would be advised to take these facts into careful consideration. Overtime work is a common motive in healthcare simulation models as has been described by these authors (Bowers & Mould 2005, Cardoen & Demeulemeester 2007, Cayirli & Veral 2003, Fottler & Ford 2002, Griffiths et al. 2005, Hall & Connelly 2006, Harper et al. 2009, Jebali et al. 2006, Lamiri et al. 2008, Lehtonen et al. 2007, Patrick & Puterman 2007, Paul et al. 2006, Rauner et al. 2008, Sciomachen et al. 2005, Swisher et al. 2001).

All of the above mentioned data can be retrieved from certain records located within or close to, the facility under investigation. The client should provide all necessary data. In order to protect the privacy of the patient, the modeller is well advised either to make patient data anonymous, or to obscure the name as much as possible in circumstances where it is essential to present a sample case.

An important issue to consider is the origin of the data. Manually entered data may contain errors; a factor which must be considered during the data analysis phase. Once awareness of this error is established, the modeller has a sound basis to identify systematic errors. However, random errors may still be undetectable.

Qualitative data is descriptive data, which describes the system and its processes. This data is best obtained from staff and patient interviews or from observations made during on site visits. Collaboration of staff and patients is essential, and therefore the modeller should invest some time in order to involve these sources of information into the project by pointing out and emphasising the key benefits of the project (McGuire 1998). This data enables the modeller to identify the routing of the items through the system and to allocate the resources which are essential for processing. Conceptual modelling, like process flow graphs, can help during the interview in order to map the processes and to serve as a discussion base. This aid is essential to support the interviewed staff member who can ascertain immediately whether the modeller has understood the nature of the process and its interfaces. Process flow graphs or business process models are a valid choice as these are easy to understand for even untrained experts within this field. Sophisticated conceptual modelling techniques such as the IDEFx family (Mayer et al. 1992) are potentially confusing and collaboration may be jeopardised.

Conceptual models are the first step to translating verbal information into an abstract model. The more staff interviewed, the more informations are at hand that can be used for the conceptual model. This is because many staff members have a different perspective on the system that they are a part of and also have different priorities with regards to work. Here the modeller must decide which routing is essential, and which one is insignificant for the investigation. The modeller must also take advantage of the vital information supplied by staff members with regards to their own experience of how long certain treatments or processes may take. Despite the fact that this information may be retrieved from the hospital records, this redundancy can be useful in order to evaluate the correctness of the quantities data.

Observation is another way of developing an understanding of the system under investigation. Here the modeller can observe how and where the resource is being used and by which process. Although promising and insightful, observation is rather limited especially in high dynamic work flow arrangements. The observer is only just able to see a fraction of the work done, with a lot of information remaining, literally, behind the scenes. However limited, the modeller nevertheless acquires information which supports the data gathered so far. A useful guide for taking notes is provided by McGuire (1998) who recommends certain strategies for questionnaires.

Once all data is available and has been analysed, conceptual modelling techniques are recommended to merge the information into the first draft model which is the basis for discussion among the stakeholders and the modellers. There are several possible techniques applicable, ranging from Petri Nets, to process flow models, over to business process mapping notations, to hence IDEFx family. A good guide on conceptual modelling can be retrieved from Robinson (2007*a*) and Robinson (2007*b*): in principal conceptual modelling describes the process from moving from the problem formulation to the definition of the system. It is an iterative and ongoing procedure which is steadily updated, even in the actual modelling phase it is recommended to update the conceptual model for documentation and illustration purposes. Hence the conceptual model is the central communication hub among modeller, client, staff and other involved stakeholders or participants.

4.1.3 Modules and Extensions

This section will explain the modelling environment, such as the required data storage possibility, the desired analysis opportunities, and the necessary declaration of local variables; followed by a comprehensive how-to, which explains the building and the mechanisms of FRA with the use of BPDs. In addition to this, ways in which the FRA can be implemented in an existing simulation model and what the modeller must consider will be illustrated. Hence a proposal for analysis of the simulation data is provided, as well as a proposal for the design of a user interface.

The aforementioned FRA modelling concept is generally applicable in process simulation, whereas its application in continuous flow simulation or agent based simulation is not viable. Therefore, within this chapter it is discussed which features a simulation programme should provide, whether it be a proprietary software package or a self assembled programming environment. First, the concept of simulation is briefly summarised and hence the essential features are highlighted out. Such features should for example enable hierarchical modelling which is in general facilitated by an object oriented simulation language. In order to maintain the discussion and the explanation of the logic on a verbal level, a conceptual modelling approach is briefly explained which will be facilitated in order to provide insights into the logic of the FRA modelling concept. These widely distributed business process model notations are facilitated and explained as a conceptual modelling technique. Process flow graphs could also be facilitated, however BPMN provides a sound structure and allows an easy adaptation to other conceptual modelling techniques (Onggo 2009).

The following modules will mainly affect the model translation phase, but will also have an indirect impact on the data collection phase, the conceptual modelling phase, and on the verification and validation phase. These impacts are discussed in section 5.5 of this chapter. In order to introduce the techniques of the modules and of the libraries, it will first focus on delivering the techniques of the modules. Assuring the correct handling and providing an understanding of the FRA concepts, provides a sounds basis with which to understand the considerations within the discussed alternations on the simulation framework.

The instructions provided in this section facilitate the BPMN flowchart notation and can be used as a widely generalised conceptual modelling technique for simulation modelling. As this technique has proved to be a valid approach for healthcare simulation modelling, it can also be facilitated as a tool in order to illustrate modelling principles. These modelling principles are explained on a relatively low abstraction level in order to provide the desired generalisability for a wide range of simulation software packages. Thus the instructions provided here can be regarded as a construction guideline and also as a reference for the functionality of FRA. Based on the instructions provided, each modeller should be able to replicate FRA within their simulation model, as long as the simulation software package supports the required features mentioned in section 4.1.3 on page 160.

The mechanism of FRA can be considered as a modelling guideline capable of modelling staff who are dynamically allocated to processes where their presence is required. A pooled resource provides the staff as a resource and the FRA mechanism allocates the staff to the designated location within one or more process chains. A process chain is a sequence of succeeding activities, which in this context is describing the patient's pathway through the healthcare facility. The explanation of the mechanism will first be kept simple by introducing only one process chain and one flexible allocated resource. A more difficult description follows, with any number n of process chains and any number m of flexible allocated resources.

System Consideration

The provided explanation of the FRA modelling concept is to be implemented in simulation packages. The guideline is general enough to be considered by any simulation package which serves the following main features: *hierarchical modelling*, *local variables* (attributes), *pooled resource items*, *random number generator*, and *customisable performance measures*. Hierarchical modelling should be supported and this is usually the case with any simulation packages based on an object oriented programming language. Local variables, also often addressed as item attributes, support the performance measurement by tracking the items routing through the system. The performance measurement must be highly customisable, as the FRA itself is already a custom adjustment to the simulation modelling program. Another important feature would be the facilitation of pooled resource items; these items stay within the system and are drawn to a certain activity when required, and hence pooled once they are released. A random variate generator is also important and delivers the appropriate essential statistical distributions required to replicate the service processing times or the inter arrival times of the customers. In healthcare many simulation modellers utilise Poisson distribution in order to model the patient arrival rate (de Bruin et al. 2007, Hoot et al. 2008, Vissers et al. 2007). Additional distributions such as Weibull (Green et al. 2006, Griffiths et al. 2005, Harper & Shahani 2003), Lognormal (Cochran & Bharti 2006*b*, Katsaliaki & Brailsford 2007) or Exponential distribution (Vasilakis & Marshall 2004) are also commonly used to replicate process times in the service sector.

The above mentioned functions are the main requirements in order to facilitate FRA in simulation programmes. However, should the modeller wish to be ambitious and include a self built object oriented programming environment, such as a Java class, the modeller is well advised to equip this environment with these features. There are several other side features which a simulation package should provide, but these are not as essential as those mentioned above. In case some side features are missing, talented modellers are able to substitute this particular feature with another workaround such as improvising by creating a routing, as for example to facilitate external databases instead of included database maintenance. Important side features considering the input of the simulation are the possibility to import and export files in order to use applications that enhance data analysis. This data analysis also benefits the customised performance measures which may be required to trace the pooled resources and calculate their utilisation. Another considerable side feature is the portability of simulation parts. This should be covered by the hierarchical modelling, but the convenience of it for the user is a good measure of how the complexity will be kept out of the simulation model so that simplicity can be maintained as much as possible. An additional support for the output section of the simulation packages is the feature to equip the modeller with standardised and customised reporting tools, database maintenance, and the ability to write model data or general data to a file. The simulation environment however should be easy to use for the modeller, or at least he / she must be familiar with the features and knowledgeable of its application. Good documentation guarantees support for the user, so that the modeller is not lost, while exploring new features in the unfamiliar

Table 4.1: Overview about the requirements towards a simulation software package in order to model FRA.

Section	**Main feature**	**Side feature**	**Optional**
Input	Hierarchical modelling	Import and export of data files	Point-click capability, Interactive run controller (debugger)
Processing	Random number generator, Local and global variables, Pooled resource items	Portability	Run-time flexibility, Reset to steady state, Independent replications, Programming
Output	Custom performance measures	Standardised and customised reports, Database support, Export to datafile	
Environment		Stability, Quality of documentation, Ease of use	

modelling environment. Table 4.1 provides a brief overview of the main and side features which should be provided by simulation packages so as to give the modeller the opportunity to model FRA.

Modelling Instructions

There is a wide range of simulation software packages available, some are for general simulation modelling, such as ARENA, AweSim, ExtendSim, or GPSS/H, whilst others are for more specific modelling like ProModel, AutoMod, which are used for manufacturing. Moreover there are even more specific packages such as MedModel which is a specially adapted version of ProModel for healthcare (ProModel Corporation 2010). These simulation packages all have a common syntax, which offers predefined general logical functions which are necessary in order to describe the process flow within a model. These predefined functions are kept as general as possible in order to allow an assembly of these functions according to the requirements to model a representative simulation model of the system under investigation. In many cases these functions or procedures are arranged as blocks which are allocated in a library. The user / modeller is hence able to assemble these blocks via drag and drop. The routing of items is facilitated by connecting these blocks with lines, which represent the flow of the simulated items. There are also invisible lines possible, which means that the item is sent to an address of a certain process. The advantage of these invisible lines is that the network does not become too confusing for the modeller. The available blocks which are essential for DES can be grouped into several categories: item manipulation category, value / data manipulation category, and utilisation category. Within the item manipulation categories the functional blocks are found to facilitate the following features: sources and drains of items, activities, queues, routing diversions and routing mergers. Batching and unbatching may either be a separate activity or grouped within the activities. Value / data manipulation functional blocks are those which offer the possibility of storing and loading data, either globally or locally, and hence apply mathematical operations to them. Also included in the data manipulation categories are those which create random numbers according to provided statistical distributions. The utility category focuses on those functions which enhance the interaction among users and the model, for example the ability to export or import data from or to the model, debugging utilities for the modeller, or general tools that allow the creation of a graphical user interface for the intended future user of the model.

These functions are represented in many simulation packages. The arrangement as well as the usability may differ, but in general these are the key elements required in order to create a valid representative DES model of a process flow system. In order to model FRA within these simulation packages, the following list (Table 4.2) summarises the essential functions required to achieve its functionality as a whole. It is recommended to make use of hierarchical modelling as well as addressed resource allocation which will help to maintain the simplicity of the model.

Table 4.2: Requirements to the simulation software package on a functional basis: description of the function, names associated within this dissertation, and name which is used in the applied simulation software package as an example.

Function Description	**Modelling Expression**	**ExtendSim example**
Item manipulation:		
Provide pooled resources	Resource Pool	Resource Pool
Send item to user definded address	Sender	Throw item
Receive item to user definded address	Receiver	Catch item
Merge item routes	Merger	Select item in <merge>
Distribute items on routes	Splitter	Select item out <sequential>
Write local variable (attribute)	Recorder local	Set <attribute>
Retrieve local variable	Retriever local	Get <attribute>
Activity of an item / resource	Resource activity	Activity
Queueing - FiFo	Queue	Queue
Counting passing items	Counter	Information <number>
Block passing item until until condition met	Block	Gate
Combine item and resource	Combiner	Batch
Release resource from item	Releaser	Unbatch
Data manipulation:		
Decide on condition (if-then-else)	Decision	Decision

Continued on next page ...

Table 4.2: ...continued: Requirements to the simulation software package on a functional basis.

...continued from previous page		
Function Description	**Modelling Expression**	**ExtendSim example**
Subtract	Subtraction	Math <subtract>
Add	Addition	Math <add>
Provide a constant	Constant	Constant
Generate random number based on statistical distribution	Generator	Random number
Write a global variable	Recorder global variable	Global array
Retrieve a global variable	Retriever global variable	Global array
Utility category:		
Create a hierarchy	Module	H-Block
Create a file for export purposes	Export	Write
Reset simulation model	Reset	

The terminology and the functionality for modelling FRA is summarised in table 4.2. This table 4.2 above is also a reference for the terms to explain and layout the principle functionality and assembly of an FRA model. In section 4.1.3 the construction and the mechanism of FRA will be discussed and explained in detail. The terms used above (Table 4.2) are chosen in order to resemble a most general understanding of the functionality. The listed functions are very basic functions which are located on a very low abstraction level. Thus, the logic functions are almost not compressible with one exception: the resource pool can be replaced by an assembly of a queue together with a block, which opens on a request for an item. This queue however requires an initial value, which resembles the pooled resources. These items must be routed in a circular way, in order to maintain the pooling character.

In order to deliver the FRA concept and functionality to a broader audience, the development, and the sequence of FRA will be explained by using BPMN 2.0 (next section). The advantage of the facilitation of BPMN 2.0 is, that this conceptual modelling technique allows a transfer to other simulation modelling environments.

Template Design

FRA modelling is applicable when the following environment is simulated: patients move along their described patient pathway, and receive treatment by staff who are not statically assigned to a specific location or unit, as staff in the radiology diagnostic unit would be. These staff are available on demand and allocate themselves flexibly to the place where their presence is required in order to enable the patient to progress on their journey through their pathway. Several different pathways exist according to the number of patient groups and cases that are treated within a healthcare facility. The FRA is still able adapt to this flexible working environment with an increasing number of patient groups, and offers a guideline which increases the detail level of the simulation model significantly without becoming complicated. The design of the FRA mechanism is divided into three steps: the first is the design of an appropriate template, which will be illustrated in a small and obvious example in the next paragraph; the second step designs the automated modelling by defining and explaining the necessary parts of the constructor; the third step is the verification, where the modeller checks whether all has been applied as intended.

In order to illustrate the FRA mechanism, a small model (Figure 4.1) is first discussed: Within this setting two succeeding processes are sequentially aligned describing the patient pathways (or process chains), which share the same staff. The treated patients enter this pathway and are treated according to the laid out pathway, first process a, then process b. A staff resource is joining the patient by providing the desired treatment, assigned as process a, once the treatment is concluded the member of staff moves back to the pool, performing whichever duties

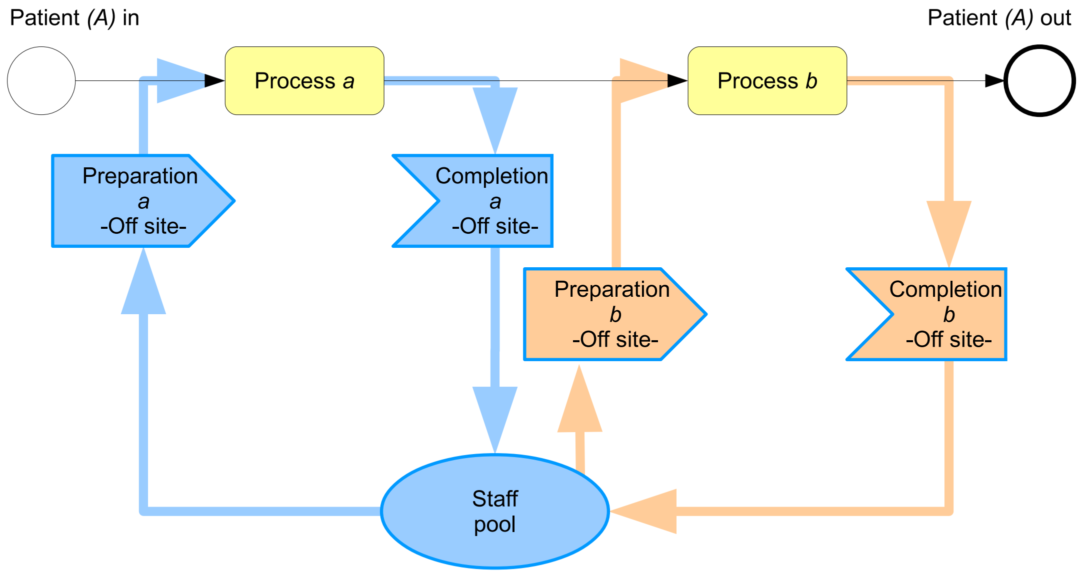


Figure 4.1: Illustration of the principle work flow described by the FRA framework – a modelling proposal limited to one shared resource and two processes.

are necessary there, while the patient proceeds to the next process step *b*. At this stage the staff resource is drawn from the pool equally to the first process step. In order to avoid a *logic deadlock*, the nurse is drawn first to process *b*, if a patient is present. The succeeding process has a higher priority than the preceding process which can be supported by observations from the presented field work (see Figure 4.1 and compare field work provided in chapter 5).

First Step: Template Layout In order to model the setting of the FRA mechanism, three modules are considered, two similar treatment modules: *"FRA-Activity"* and the resource pool: *"FRA-Pool"* (Figure 4.2 and 4.3 respectively). As a reference for the terminology, please refer to Table 4.2. The FRA-Pool which allocates staff to two FRA-Activities, is constructed as follows (Figure 4.4): a *resource pool* holds the number of shared staff resources, which is simulated by a function that provides either pooled resources or an alternative queuing-blocking logic. This alternative may be facilitated in order to emulate the behaviour of the *resource pool*. A *recorder* writes a local variable to the staff item which sets an identifier to the staff in order to allow time and allocation evaluation for analysis purposes. A *splitter* diverts the staff to the resource which requests said staff. Only one staff member can be requested at a time. The logical assignment of staff is allocated within the FRA-Activity. A *sender* retrieves the address of the requesting activity and sends the staff to this destination accordingly. Having left the FRA-Pool the staff member is occupied within the FRA-Activity. The FRA-Pool remains inactive until the *receiver* retrieves the returning staff member. The *receiver* draws the address from the sender in order to place the staff member in the correct pool (only required if there are several pools available). Following this, the staff member is led through the *merger* back into the *resource pool*. Next, the *retriever* reads the entries made for analysis, such as time and location. After this the staff member is placed back into the *resource pool*. By finishing the FRA-Pool, the modeller should consider creating hierarchy modules on the *sender* section and on the *receiver* section. These are essential for the second step of the FRA design, which generates automated modules. These hierarchical groups are referenced as *"grouped senders"* and *"grouped receivers"*.

Modifications are possible at any stage in various ways, for example activities may be included before the distributor or after the merger, which either represent the preparation time or the subsequent post processing. Applying these activities follows the description of the concept of multiple participant pathways (explained in Section 4.1.1 on page 146). Introducing these modifications allows adding more reality to the daily work pattern of a healthcare employee.

The FRA-Activity is one part of the patient pathway, where the patient is receiving treatment by the accompanying staff member who is allocated to this activity. The general understanding of this procedure is that staff and patient are merged in order to complete this process. However, in order to assign the right staff member to the right patient, a number of functions are necessary and will now be explained . This module requires the following interfaces:

- *The item* (patient) input and output;

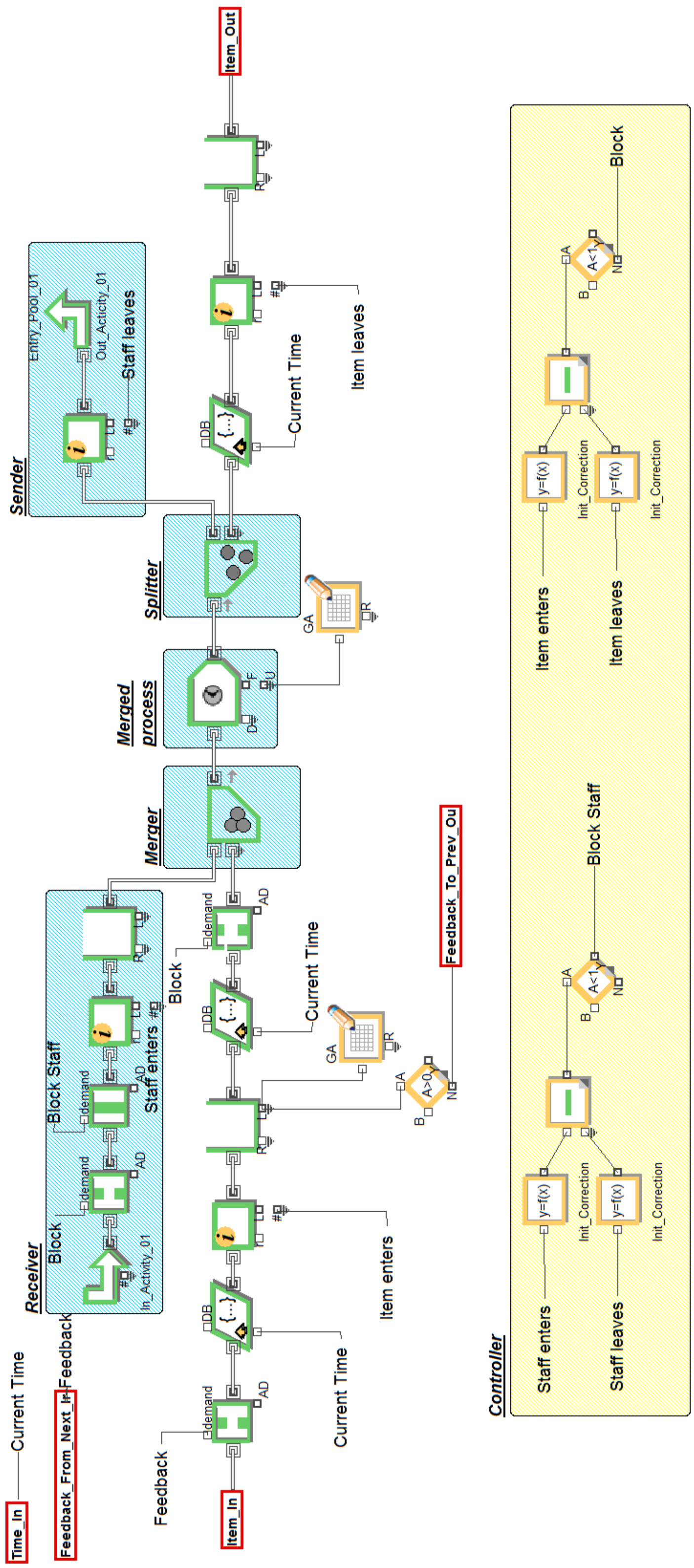


Figure 4.2: Illustration of an activity considering FRA.

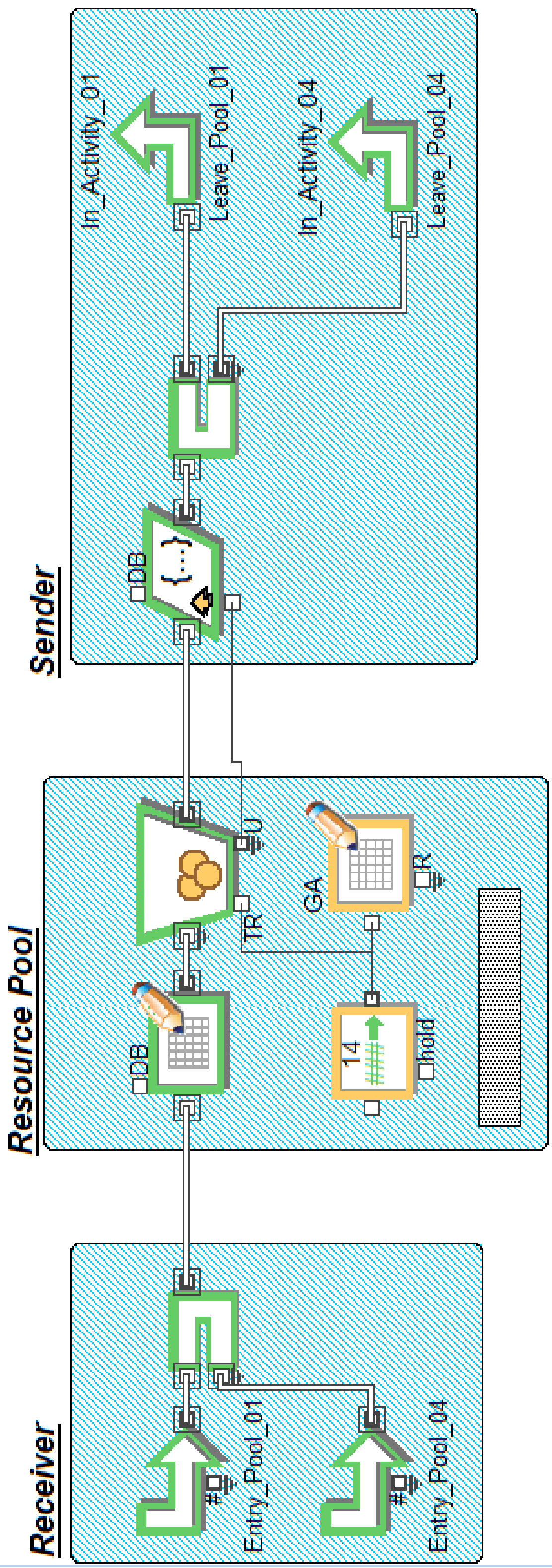


Figure 4.3: Illustration of a staff pool considering FRA.

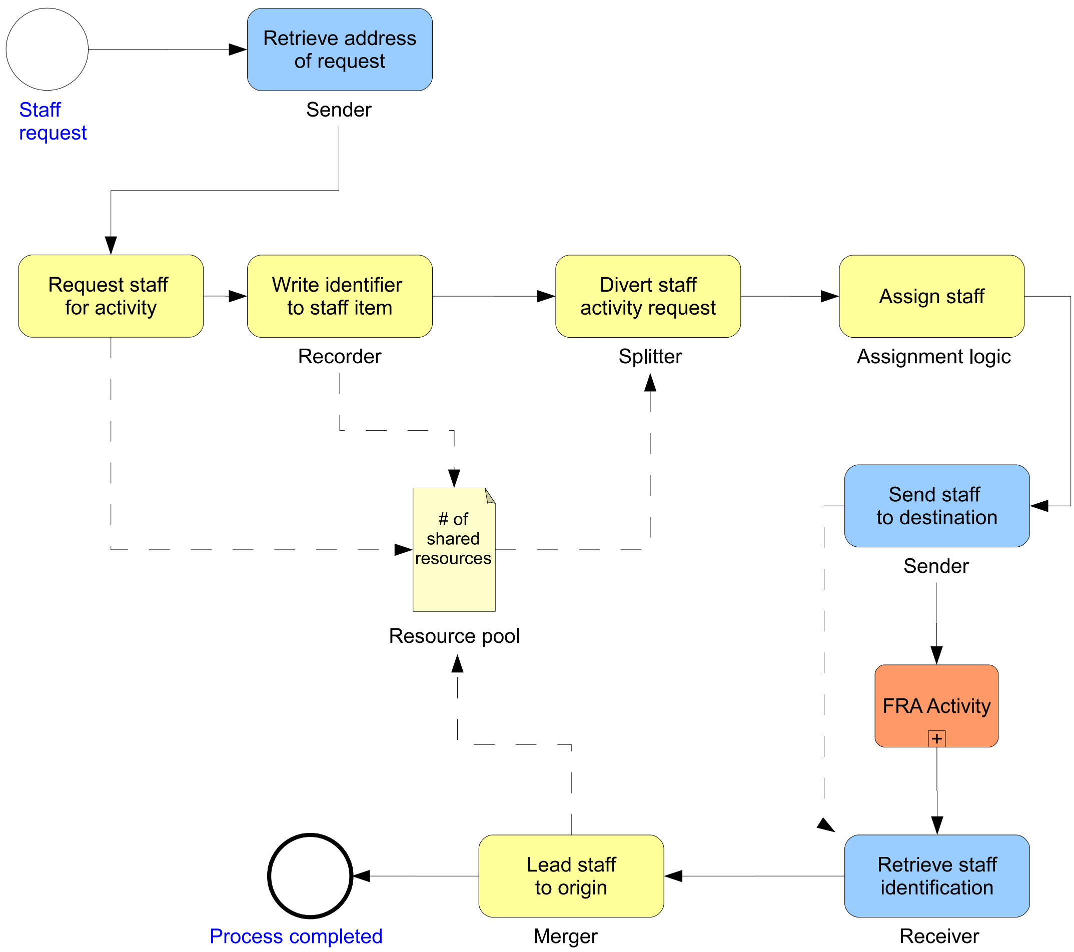


Figure 4.4: Illustration of the FRA mechanism in BPMN.

- *A clock* that delivers the current time;
- *Address identifier* which indicates the process chain and the actual activity;
- *A feedback channel* from the succeeding FRA-Activity;
- *Another feedback channel* to the preceding feedback channel.

Address indexes are retrieved from the address identifier and are essential in order to allocate the right staff resource to the right process. The reader can orientate him or herself with the BPMN graph provided (Figure 4.4) and can also refer to the example extracted from the simulation software package (Figure 4.5).

The process can only be initialised if the activity itself is in an idle state, which means that any previous activity must be concluded and any associated resource must be withdrawn. To ensure this, a logic controls the number of resources and number of patients within this module. This control is attached to a block which allows access to the patient. As soon as the patient passes the block, his / her presence is noted by the *counter* and this count is made available for the *controller*, which closes the block for any subsequent patients. The controlling unit subtracts the number of entered patients from the number of leaving items; if the result is smaller than the allowed capacity then the block is closed. With the allowed capacity, the user can set how many patients may enter at once to receive this treatment. Depending on the permitted capacity, a queue is required in order to gather the patients for further processing. A *recorder* notes the time at which the patient enters the certain FRA-Activity; the time is recorded as a local variable of the patient. Once the patient has entered the FRA-Activity, a staff member is called by the *receiver*, which sends the address identifier to the *sender* in the FRA-Pool. The staff member can enter the FRA-Activity once both aligned blocks are opened.

Both blocks are controlled by the *controller*, the first one opens as soon as a patient enters the FRA-Activity, while the second is initially open until the according staff member has entered the FRA-Activity. A *counter* detects the staff member

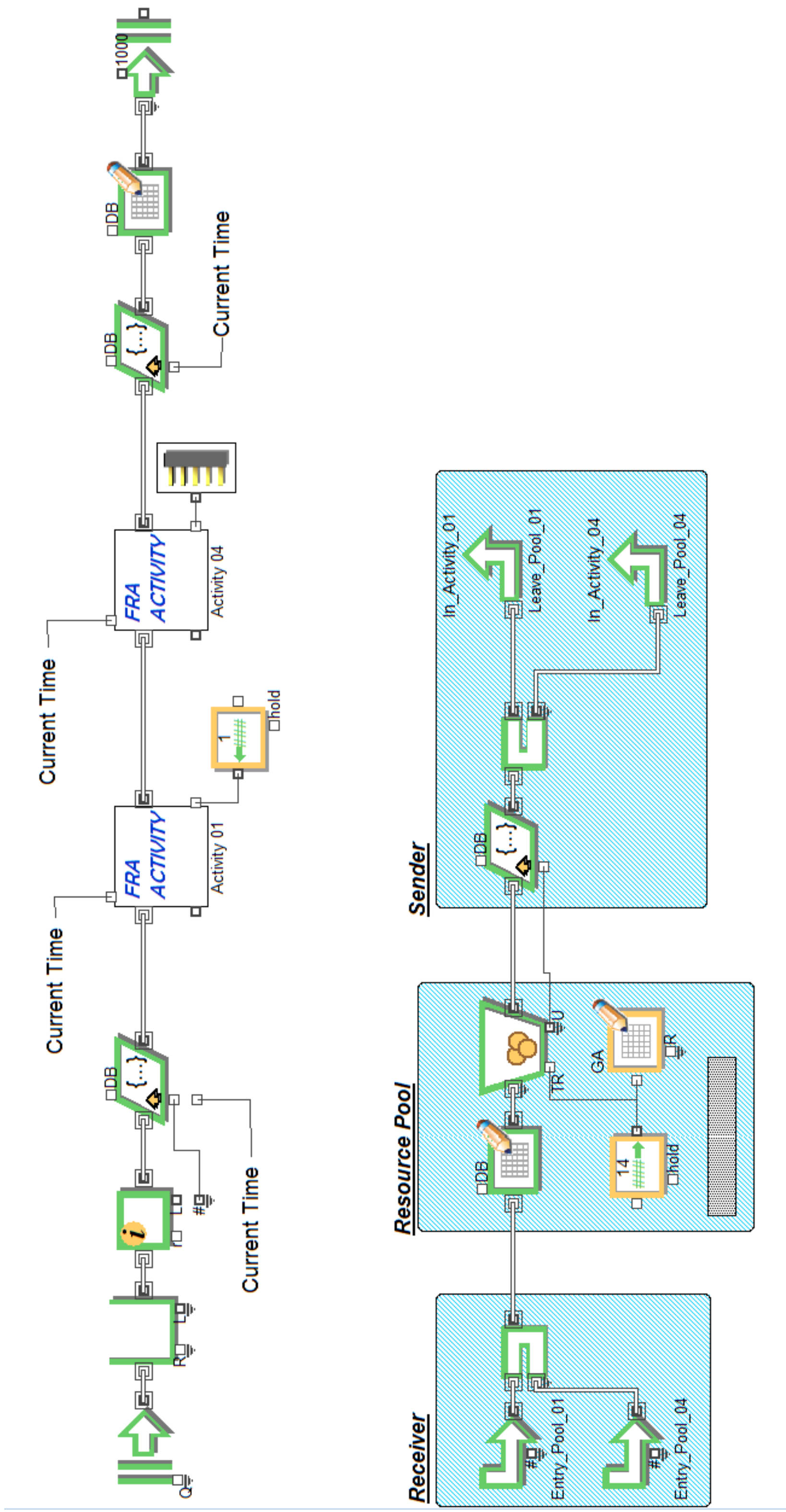


Figure 4.5: Illustration of an example applied in a simulation software package.

and sends it to the next *controller* which subtracts the number of entered staff from the number of leaving staff. The *controller* opens the block on the staff entering side as soon as the result is smaller than the allowed capacity. A *recorder* writes the entrance time of staff to its local variable.

Once the staff member and patient are in place, a combiner joins these resources and triggers the start of the actual activity within the FRA-Activity. The activity can be configured to hold an infinite number of items, as the capacity is set by the controllers within the FRA-Activity. However, some simulation packages which offer multitasking, should be considered, whether or not this feature is really wanted here. The timing of the activity is provided by a *generator* which can retrieve numbers based on a statistical distribution. Once the activity is concluded the *releaser* separates the staff from the patient and sets them on different routes. A *recorder* placed on each route stores the time for both activity members. A *counter* on both exit routes then sends the number of passed items to the *controller*. On the staff side, the *sender* delivers the index address to the receiver on the according FRA-Pool which is the recipient of the staff. The patient now leaves the FRA-Activity on his exit route.

This description above is illustrated in two diagrams (Figure 4.4 and 4.5 respectively). In order to facilitate the next step, the modeller should consider creating hierarchical modules which summarise the entrance as well as the exit of the staff member. These hierarchical modules are referenced as *"staff entrance"* and *"staff exit"*. After the hierarchical module, a *combiner* is present in case there are several resources involved and required for the process. This *combiner* should be considered in the second step (automated modelling) as well. Equivalent to the *combiner* of the *"staff entrance"* a *releaser* is needed before the *"staff exit"* which separates the resources. The modeller should consider these modules as the design templates, which will be altered according to the desired degree of complexity. However, at this stage, the modeller is free to make any modifications or adjustments that are to his liking, for example, adding an activity on the staff entrance or exiting side, which reflects the walking distance and complies with the concept of multiple participant pathways (explained in Section 4.1.1 on page 146).

FRA-Activity and FRA-Pool work together in a mechanism, which will now be established. The above description is the formal set-up, but in order to provide it with more flexibility, some adjustments must be considered. The number of *receivers* and *senders* on the FRA-Pool is dependent on the number of allocated FRA-Activities, for each FRA-Activity that a member of staff is assigned to, an equivalent amount of *senders* and *receivers* is necessary. This is necessary in order to address the virtual routes between the resource pools and the actual activity. If there are, for example, two FRA-Activities in the process chain, then two *senders* and two *receivers* are required. If another identical process chain is added, then four are required respectively and so on and so forth. It can now be seen that this adds a high degree of complexity, unless there is no automatism included within these two modules, which is explained shortly in Section 4.1.3. Another factor which would increase the complexity would be if more pooled staff groups were to be considered. In this case the equivalent amount of senders and receivers would be required on the FRA-Pool side, but also the creation of additional routes would be needed to facilitate the entrance of this particular new group. A *constructor* is also required, which allows for the necessary adjustments on both module sides. This *constructor* must be included during the modelling phase. This is because before the actual run of the simulation the *constructor* must apply the final creations in order to adjust to the degree of complexity. This automated modelling may not always be supported in the simulation software package.

Modelling Automation

Automated modelling requires planning and consideration with regards to resources. This step contributes to planning the layout section and the programming section. The programming section influences the automated modification of the model. The layout is beneficial in most simulation software packages as it allows a clean layout even on a high complexity degree. This mapping can be allocated by providing mapping instructions, however, each individual simulation software applies different procedures.

The creation of a constructor may also be different for each simulation package, depending on the simulation run technique that is used by the developer. These constructors may be reserved in a special section. This section may be executed before runtime of the simulation, or may be executed in the simulation program as an own module, which is executed during the initiation phase, just before runtime. Here it is important to refer to a renowned example of similar fieldwork, where a simulation software package has been facilitated which describes the creation of a programme module which generates the required hierarchies automatically, according to their required addressed allocations. The code is presented in Nassi-Schneiderman-Diagrams (Nassi & Shneiderman 1973) which should be easily translatable in any programming language which is provided in the simulation software.

The basic principle of this module is explained here (see Figure 4.6). In general the first step within this module is to retrieve the degree of complexity, by identifying the number of entities within each of the process chains. This number is used as an address reference and as an identifier for the senders and receivers within the *"staff entrance", "staff exit"* and the *"grouped senders"* as well as the *"grouped receivers"* modules. The code address can be set in three separate loops which create the four different modules according to their number. The first loop creates for each process chain a group sender and receiver in the FRA-Pool module. The second loop fills for each entity in a process chain, the grouped sender and receivers with the required addresses. The third loop is a two dimensional loop which loops through each process chain element and creates for each staff group the staff entrance and staff exit modules.

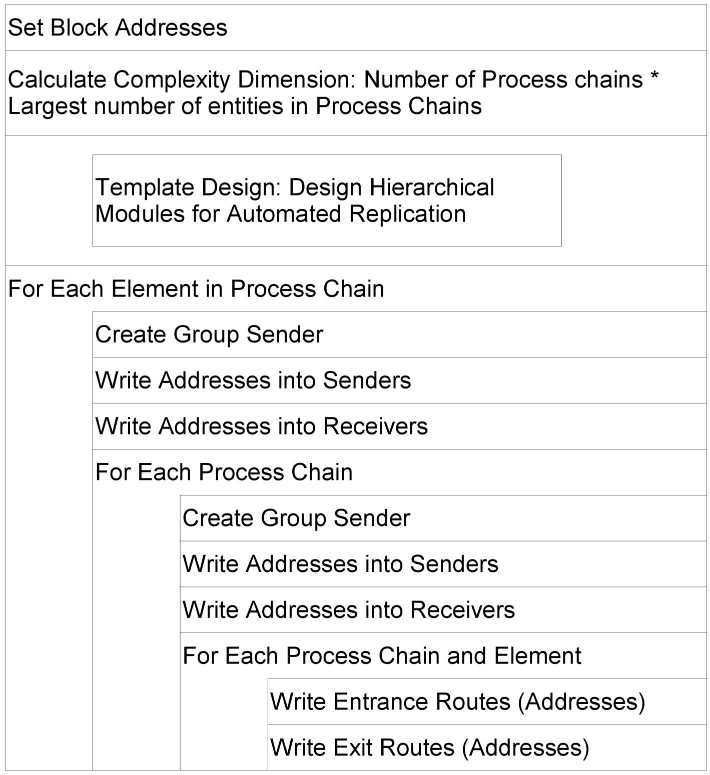


Figure 4.6: Structogram displaying the procedure to set up and programme the automated model.

Error Diagnostics

The third step in generating the FRA mechanism is ensuring and verifying that all is laid out as intended and that the resources are addressed correctly. Here the modeller might utilise the debugging tool at hand in order to trace the resources and items. However, once these instructions are followed precisely, no complications should occur. It is also recommended to use additional debugging to analyse the recorded timings of staff resources and patient timings. Investigations on queues allow for the identification of errors such as undesired blocking due to unassigned resources.

Generalisability

Simulation is a flexible tool which can be applied in many domains. This flexibility can also be observed in DES, which has a high potential for providing a sound information basis for decision makers. Flexibility also results in a high degree of diversity, which can be seen in the high number of available simulation software packages. However, because of the powerful constructs provided within their software, a FRA approach could not be retrieved by scanning the recent literature. In order to facilitate a broad spectrum of simulation modellers, a check-list is provided which summarises the essential features which are necessary in order to model FRA within the desired simulation software package. The principles of BPMN are introduced which will later be used to explain the construction and the mechanism of FRA. The more broad this explanation the broader the impact will be among the simulation modellers.

Application Example

In order to illustrate the application in a simulation package, the following example is extracted from the actual fieldwork, which is explained in detail in chapter 5 on Page 206. Because of the latter explanation, the focus here is set on the creation of the modules, and their employment. It was identified that the ED had three different units, therefore three main process chains were modelled each of which facilitated the treatment of several patient groups. Involved in this treatment were six different staff groups (cleaners, porters, nurses, doctors, senior doctors and consultants), and four other resource types (cubicles, trolleys, wheelchairs, and general medical equipment). The process chain entities represented the treatment activities within a cubicle. The process chains were divided into eight treatment steps, whereas six involved the patient directly. After the second treatment step an optional diversion represented the delivery to a diagnosis facility, like x-ray or computed tomography (CT). The diagnostics were made outside of the process chain, and the patient was sent back to his process chain after completion of the diagnosis procedure. Subsequent to diagnostic were three different treatment steps involving the patient. Prior to and after these treatment steps, preparation processes were applied to the cubicle. An example on the arrangement of the template can be seen in Figure 4.7.

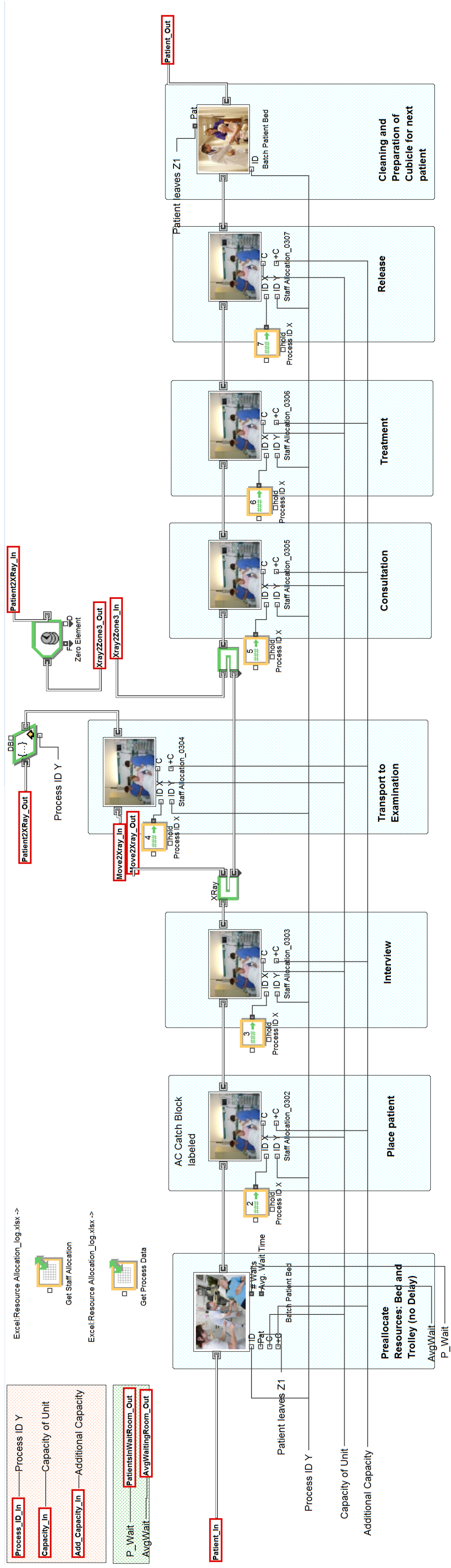


Figure 4.7: Process chain displaying the passive pathway considering FRA and MPPM.

Zone 2	Amount	Amount	Amount	Amount	Amount	Amount	Amount	Amount	
Steps: / Resource	Prepare	Place Patient	Interview	Transport to Examination	Consultation	Treatment	Release	Cleaning / Maintenance	Total
Time [min]	4	7	15	6	15	30	8	4	*159,57*
Standard Deviation	4,43	7,74	16,60	6,64	16,60	33,19	8,85	4,43	*176,55*
Location	1,75	3,07	6,58	2,63	6,58	13,16	3,51	1,75	*70*
Patient		1	1	1	1	1	1		*6*
Cubicles	1	1	1	1	1	1	1	1	*8*
Trolleys	1	1	1	1	1	1	1	1	*8*
Wheelchair		1		1					*2*
Cleaners				1				1	*2*
Porters	1	1		1			1		*4*
Nurses		2	1			1	1		*5*
Doctors			1		1	1			*3*
Senior Doctors					1	1			*2*
Consultants					1				*1*
Equipment			1			1			*2*

Figure 4.8: Control table to allocate staff, resources and process timings.

According to the first step of the FRA development, the template of the FRA-Pool for the nurses is laid out as follows; a resource pool contains the employed nurses who are shared among the units of the ED. A recorder identifies the leaving time before passing the splitter. A hierarchical block the *"grouped sender"* combines the senders for each unit (process chain). The senders are initially equipped with provisional addresses in accordance with regulations enforced by the compiler of the simulation software package. *"Grouped receivers"* on the receiving side are also equipped with provisional addresses . Before placing the staff resource into the pool, an activity must be completed, which represents the documentation of the patient case. An identical setup is applied to the other staff resources, while the equipment resources differ in the documentation aspect.

The FRA-Activity is structured according to the first step of the template instruction, where blocks and controllers are managing the number of resources which are involved in the process. In order to ease the configuration, a spreadsheet calculation table is used where the user can set the number of required resources for each process. In addition to the number of resources, the user is also equipped with the possibility to set the process times for each activity (Figure 4.8). The numbers of resources are sent to the controller by an input and output routine provided by the simulation software package.

Deviating from the above described FRA-Activity template development process, the addresses of the *"staff entrances"* and the addresses of the *"staff exit"* must be provided with provisional addresses, which are overwritten in the automated modelling step.

The automated modelling is facilitated by implementing the code in a library block module, which offers an interface that allows automated modelling as a runtime environment. The code, as described above, as well as the required interfaces must be considered. These interfaces consist of the location of the addresses of the senders and receivers as well as the number of resources which must be considered. The automated modelling module overwrites the previous provisional addresses. Hence, when this step is completed, the model is executed automatically for the first time. Modellers are well advised to choose a short execution time, in case anything goes wrong. The third debugging step is essential to prove the intended validity of the model.

The instruction provided gives guidance in designing a template and also a guideline for the logic provided within the FRA. In order to complete the model in a structured way, some alternations are needed which require a certain amount programming. Due to the manifold programming languages provided within many simulation software packages, the author chose to deliver a pseudo code, which can be easily translated into any programming language. The above illustrated instruction set shows, that adding complexity to a model does not necessarily result in a complicated model, as long as the modeller follows the structure. Structuring thought and method is the best way to guarantee and maintain low complication levels even though the complexity increases.

4.1.4 Discussion about Framework

The FRA-block which is proposed in this field work allowed for including the activities of limited connected resources such as medical staff, who are flexibly allocated within the ED and are dependent on each others' contribution. Prepared patients ready for treatment cannot be treated if the specialist is not available and it is for this reason that queues build up. In the conventional modelling procedure the inclusion of the active pathways would result in a large network which is difficult or even impossible to administer and maintain. Using addressed connections which are virtual not visible, allows the location where the resource is applying its work to be specified. Therefore, the modeller need only see where such a resource is required and specify this in an external spreadsheet. The construction of the model is made automatically. Before the model can than finally be executed, final manual adjustments are necessary, but overall the additional work for the modeller is minor.

With a model at hand which includes the concept of active pathways, more information regarding the flow of the patients and of their interactions with the resources can be retrieved. Another important source of information is that data can be retrieved which describes the work flow of the staff within the ED. In conclusion, applying the concept of active pathways increases the transparency and provides a thorough understanding of the system for its users.

4.2 Potential Application Fields for Flexible Resource Allocation and Multiple Participant Pathway Modelling

The application of FRA in combination with MPPM can be transferred to other fields within the healthcare domain as long as the requirements are met. The following checklist helps to identify whether a certain application field would be applicable for FRA and MPPM. The checklist in the next subsection should be considered with care, because a successful application is not necessarily guaranteed even if all the points are met; nor can the application be concluded if one or two points are not answered positively.

4.2.1 Consideration for Application Flexible Resource Allocation to Operating Theatres

Due to the previously provided checklist, it can be investigated whether FRA in combination with MPPM is applicable to different fields. A worthwhile consideration would be whether operating theatres are a suitable area. Many hospitals still fill out documentation and conduct procedures using a manual pen and paper method. A similar hypothetical scenario setting, as it has been applied to ICUs would therefore deliver valuable insights. Before the process chains themselves are investigated, a checklist (as in section 4.1.2 on page 153) is hooked, if the FRA and MPPM is applicable:

- Processes are sharing the same resources, e.g. reserve pool nurses.

  N This is not the case, as due to health and safety regulations an advance staff assignment must be made. Medical staff are not changing from one patient to another during the process.

- Resources are located in a demand driven manner.

  N Demand is high, due to the high costs, but operations are strictly planned – no spontaneous allocation of resources.

- The system is experiencing high demand.

  Y This is definitely the case.

- Unexpected queues are appearing which cannot be explained in any other way.

  N Should not be the case in any operating theatre.

- Previous simulation or any other analysis method did not / or would not deliver satisfying results.

  N There are numerous positive examples, Bowers & Mould (2004) is just of them.

- Multiple flows of different items/participants types are present.

Y This point would also be applicable.

According to the above hooked checklist, operating theatres are not a suitable environment for FRA and MPPM, even though one might expect it to be a worthwhile and interesting application field. Scheduling, DES or other operational research techniques are potentially easier and more feasible approaches. Surgeries must be well planned and organised – FRA in combination with MPPM intends to provide answers to areas, where spontaneous resource allocation due to high demand is present and makes planning and scheduling in an ordinary manner difficult. Despite the fact that the checklist provided a negative outcome, one might like to apply FRA and MPPM for research reasons. However in the opinion of the author this is not recommended, as the interpretation of results would be difficult. In addition answers may be provided which would have also been achieved with an ordinary approach of DES.

4.2.2 Potential Application in Intensive Care Units

ICUs yield the highest costs per bed in a hospital. The main reasons for this are to do with the use of vital monitoring and respiration equipment. This means that patients require constant supervision and more care is required for intensive care patients when compared with other inpatients. Indeed, approximately 30% of costs relating to inpatient beds are caused by 8% of total patients (Cahill & Render 1999). Due to these high costs and the high impact of complications to subsequent processes, operational researchers attempt to optimise processes within the ICU. This done in an attempt to achieve smooth work flow with an optimum bed utilisation, or with the best possible distribution of resources at limited costs. Table 2.3 on page 86 provides authors who have applied process simulation in their investigations.

High utilisation is an aim which is related to high cost. Patients arrive at random rates and planning is difficult. In cases of high demand, patients with lesser severity grades are refused or referred to other ICUs. The ratio of doctor to patient is 1:3 and nurse distribution is equivalent to the doctors' ration in an observed hospital.

Patients therefore share the same resource of medical staff. Doctors and nurses must follow procedures and work flow guidelines which cover the washing of hands, seeing the patients, providing care and medication as well as documenting their activities. Let us assume the following scenario which is formulated to ascertain whether ICUs may be a feasible environment for the application of FRA and MPPM. The patients' journey through the ICU can be hypothised in the following pathway:

1. Admission;
2. Stabilisation;
3. Continuous monitoring of vital signs;
4. Provision of treatment and care;
5. Preparation for surgery;
6. Transport to surgery;
7. Collect from wake up room;
8. Provision of post surgery care;
9. Stabilisation;
10. Ongoing provision of care and treatment until patient is ready for referral.

The above pathway may include iterative loops depending on the condition of the patient and his / her requirements. In some cases surgery may even be repeated if the result has not been satisfactory. On the staff side the work flow may be illustrated as:

1. Wash hands and wear disinfected protection cover;
2. Check patient file;
3. See patient;
4. Check vital signs;

5. Document vital signs;

6. Address patient directly;

7. Note response and act accordingly;

8. *Apply treatment and care*;

9. Document measures, medication and vital signs;

10. Leave patient;

11. Remove disinfected clothing and wash hands.

The patients journey can be described as a passive pathway, while the staff pathway can be seen as the active pathway, because the outcome of this pathway influences further activities. The process stage number 8 indicates where the passive and active pathways merge. In ICUs, a limited amount of patients can be treated simultaneously and there are multiple staff types such as senior doctors, doctors and nurses. Considering this hypothetical set up, it can be said, that ICUs in general are a suitable application field for FRA and MPPM as they provide all necessary features, which are postulated in section 4.1.1.

Scenario investigations can here be applied and can provide answers with regards to how much of an impact an automated documentation aid would have on the utilisation of staff. An example of such an aid would be having a patient data management system (PDMS) installed. This scenario primarily contributes to the active pathway. This scenario would be incomplete only the work flow (active pathway) was simulated, because the environmental impact would be ignored. On the flip side, focusing this scenario on the patient journey (passive pathway) only, is hardly feasible, as the patient is not directly involved in the documentation activity and has therefore little or no influence on this activity. It can therefore be said that MPPM and FRA is a valid approach to ICUs and to investigate the utilisation in case of documentation improvements.

An application of the proposed modelling technique for this investigation can be validated with the results of a study conducted by Bosman et al. (2003), where a PDMS is introduced in an ICU in comparison with a control group which continued to document the patient data on paper. The results indicated that 29 minutes of documentation effort is saved per nurse shift with the introduction of a documentation aid such as a PDMS.

4.3 Application of FRA in Queuing Theory – Practical Consideration on Utilisation of EDs

Modelling under the consideration of active and passive pathways is investigated with a theoretical evaluation in order to highlight that the concept is applicable in bounds of the queuing theory. Additionally, it is the aim to identify certain regularities and limitations for the concept MPPM which is facilitated here by investigating flexible resource allocation. The resources here remain passive with no active pathway involved. The consideration here is the first step of many research opportunities which can widen the application range of DES (Thorwarth et al. 2009). Recent research and implementation of simulation applications have tended to focus on manufacturing and production facilities whereas the dynamics of servicescapes, such as flexible workload of employees, has received less attention. This flexible workload is usually described as "multi-tasking" – not to be mistaken with the actual term multitasking which specifies more than one task to be computed at the same time. In this context, flexible workload describes a worker dealing with several different tasks in a flexible manner within a given time frame.

An example of flexible workload in the servicescape is EDs in hospitals, where nurses deal with several patients within the department within the same time frame. During periods of high patient demand, the work environment is stressful and burnout symptoms are a common occurrence. The rate of psychological illness has been known to vary from 17% to 33% among healthcare workers in the UK

(Michie & West 2004). One major concern of healthcare providers is the quality of service delivered; high patient demand causes a workload resulting in high utilisation of staff which in turn has a significant negative impact on error rates. It is therefore mandatory for healthcare managers and administrative personnel to identify under what conditions their processes should run in order to provide a safe and healthy environment. However, this flexible workload environment appears complex and highly dynamic to the observer. Simulation modelling attempts to mimic such work environments, requiring a logistical overhead which adds this special feature to the initial package of available commercial packages. Very little research has been conducted to investigate the impact of flexible workload on the overall system performance. Therefore an investigation within a simulation of an emergency department is undertaken in order to describe the impact of the number of staff to the overall utilisation within a process chain that incorporates flexible workload.

The model developed offers insights into the dynamics of a flexible workload process chain and demystifies its complexity for the benefit of an increased transparency and better understanding of the mechanism of flexible workload process chains. This section aims to demonstrate how simulation can be used in order to find a mathematical description of complex and dynamic systems that are difficult to capture analytically in an algebraic manner. Hence, the mathematical description is presented in an equation which shows how the utilisation of a flexible workload behaves in conjunction with numbers of staff and patient arrival time. A comprehensive description is given of the flexible workload process within the ED of St. Vincent University Hospital in Dublin, (Chapter 5).

4.3.1 Methodology

A detailed simulation modelling for an ED is developed, with a focus on the allocation and utilisation of its resources. The ED is placed in a university hospital which serves approximately 50,000 patients annually. EDs in Ireland provide a set of services including primary, secondary, and tertiary care. Therefore, the ED faces a very high demand. Government funds are not adequate to solve all of the issues of the ED. This information can be retrieved from the emergency task force report which describes symptoms such as hospitals not being able to provide the necessary amount of beds. This results in emergency patients having to remain in the emergency department for significant periods (Health Service Executive (HSE) 2007). Decision makers therefore strive for solutions which help to identify their bottlenecks and optimise their patient flow.

During the analysis phase, the nurses complained about their high workload and stress level caused by what they called "multi-tasking". Their work can be best described as a spontaneous allocation of wherever their work is needed most. The ED is identified as a set of several integrated and connected processes with the focus set on the staff. It also features a high dynamic alternating environment. A model is derived from descriptions and observations (see Section 3.3.2). This alternating of staff between the processes can be best modelled with a discrete event simulation approach due to the flexibility and robustness of this approach. However, a logistic overhead is necessary in order to mimic the flexible workload allocation. In order to understand the mechanism of a flexible workload, an algebraic expression is found which allows a further insight into the dependencies of over- and understaffing in relation to the patient arrival time. This driven expression is the first step in the optimisation process which aims to achieve the equilibrium between staffing and service quality level.

This section exhibits a comprehensive application of simulation modelling and its role is to analyse a complex dynamic environment. It also describes analytically the relationship between various entities in the uncertain system. This analytical model delivers three benefits:

(i) An increased understanding of the system;

(ii) It supports an optimisation process;

(iii) It provides healthcare decision makers with a formula that can be used to depict the staff utilisation and the threshold number of staff.

Flexible Workload Model

To find a description of the utilisation ρ in dependence of the interarrival time T and the number of available staff n, the following model is investigated to consider flexible workload management. The model as illustrated in Figure 4.9 is one of several process chains within a large ED simulation model. The model presented here is extracted from the detailed ED model in order to investigate the mechanisms of a flexible workload environment. The investigated process chain is a one dimensional representation of a series of m_i tasks that are sequentially completed by n personnel allocated in the staff pool. The parameter M describes the number of tasks aligned in the process chain. A task can only be completed by the presence of staff. That means that if no staff are available for a certain task, the patient would therefore have to wait for the next nurse to be available. To avoid blocking a staff assignment, logic arranges that the furthest processed patient gets the highest priority. Queues between all processes buffers all patient waits.

The following is an example of such a process chain: patients arrive at an arrival rate λ. After having registered and occasionally having waited in the waiting room, the patient enters the treatment process m with M tasks (compare Table 4.3). The first task for the nurse is to triage the patient; followed by placing the patient in the cubicle or bed and making certain arrangements. The third task is usually to take samples of the patient as requested by the consultant or the doctor. After that, the nurse arranges the requested diagnosis (guiding patient to x-ray, ct, or ultra sound). The fifth task involves the nurse tending to the patient's needs, while diagnosis and results are on the way. Finally, the nurse must arrange the patients' referral.

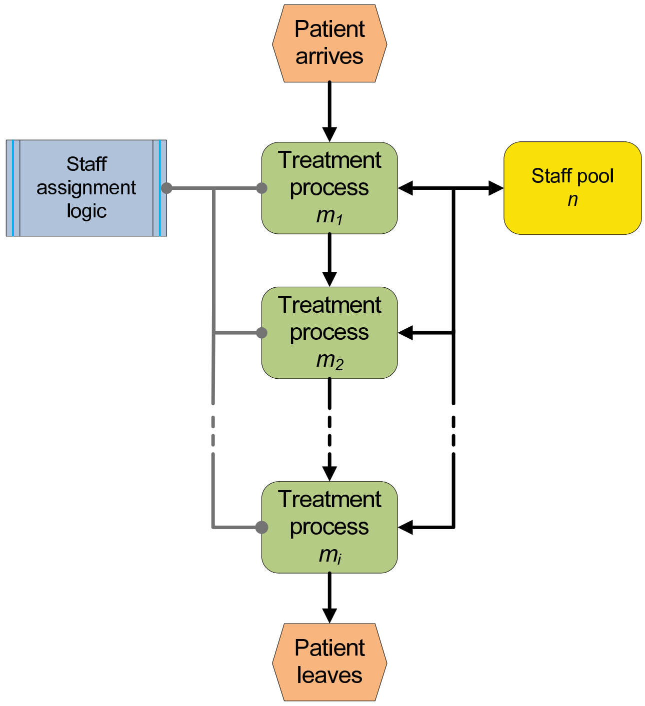


Figure 4.9: Simplified multitasking model to illustrate flexible resource allocation.

Table 4.3: : Example for nurses' tasks in a flexible workload environment.

Task number i	**Description of the task** m_i **for nurse** j
1	Triage patient
2	Place patient in cubicle / bed
3	Take samples (blood, tissue, etc as requested)
4	Arrange diagnosis (x-ray, ultra sound, ct, etc)
5	Pay attention to patient needs
6	Make arrangements for referral

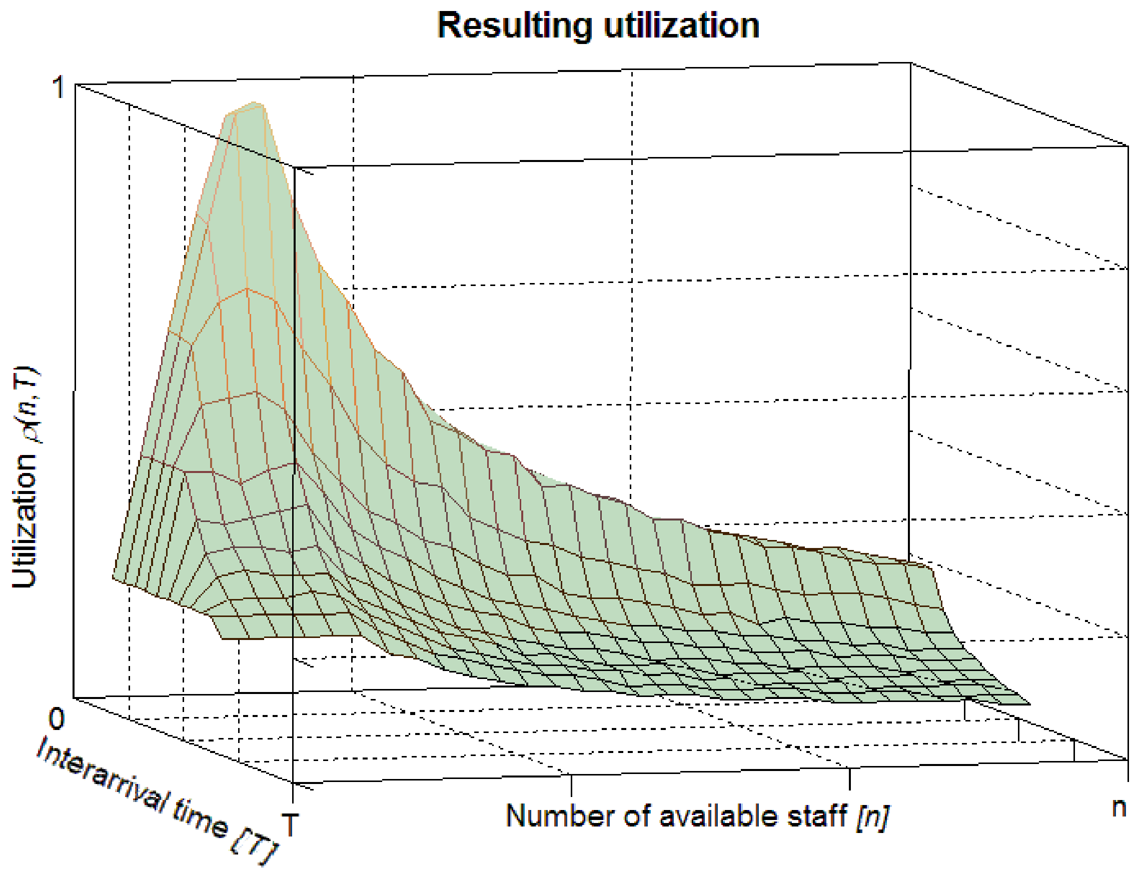


Figure 4.10: Simulation results showing overall resulting utilisation $\rho(n,T)$ of a flexible workload environment, in dependency of the patient interarrival time T and the number of staff available n.

Simulation Results

Simulation experiments of the above described model deliver the graph displayed in Table 4.10. The patient interarrival time is set to be Poisson distribution which was drawn from the hospital records. The overall utilisation was recorded taking into consideration a warm-up period. The process service times of the tasks were normally distributed.

The overall utilisation $\rho(n,T)$ is measured in dependence of the available number of staff n and the interarrival time T, where the interarrival time T is the reciprocal of the arrival rate λ. Figure 4.10 displays a number of trends, such as linear areas, a plateau and a hyperbola area. In order to analyse these trends the overall utilisation is subdivided into its components (utilisation of staff and utilisation of activity).

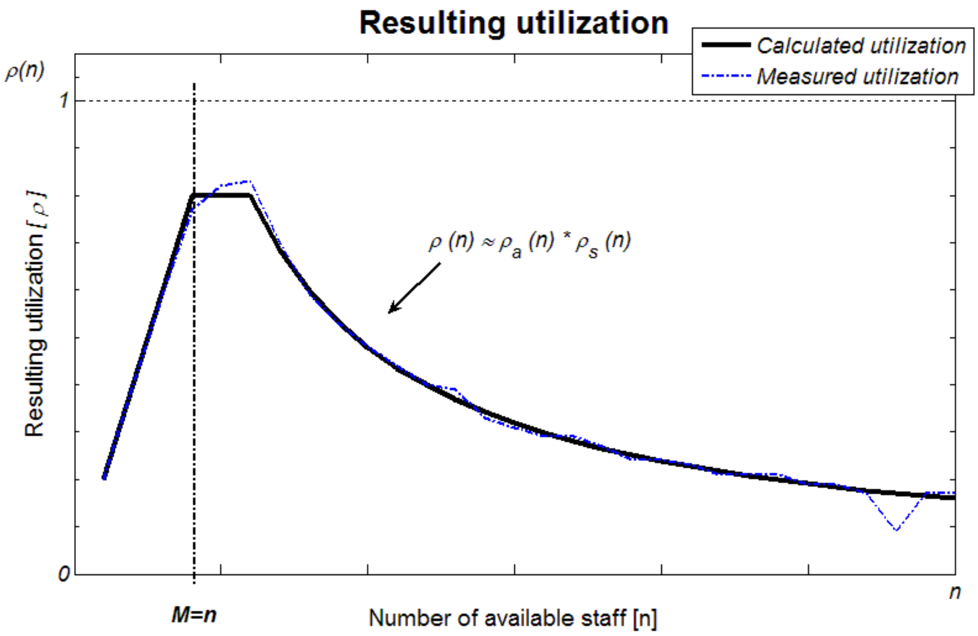


Figure 4.11: The simulation result (dotted line) and the estimated calculated model (solid line) for the overall utilisation $\rho(n)$ for a specific arrival time t in dependence of the available staff n.

Analytical Model

DES is a practical platform to facilitate queueing theory. A comprehensive description of its application in relation to queueing theory is provided by Law & Kelton (2000). The here investigated model is usually described as tandem queues, where the output of one stage affects the input of the other model. An analysis on these effects are provided by Glasserman & Kou (1995). Within the model of the analysed ED however, the influence of the available staff n and the number of tasks M in relation to the interarrival time is investigated.

A combination of several dependencies influencing the overall utilisation was shown in 4.10. In order to derive a function that is able to describe the flexible workload environment, the result was investigated and interpreted by its components. The main focus was on the available number of staff at a certain arrival time slot t (Figure 4.11).

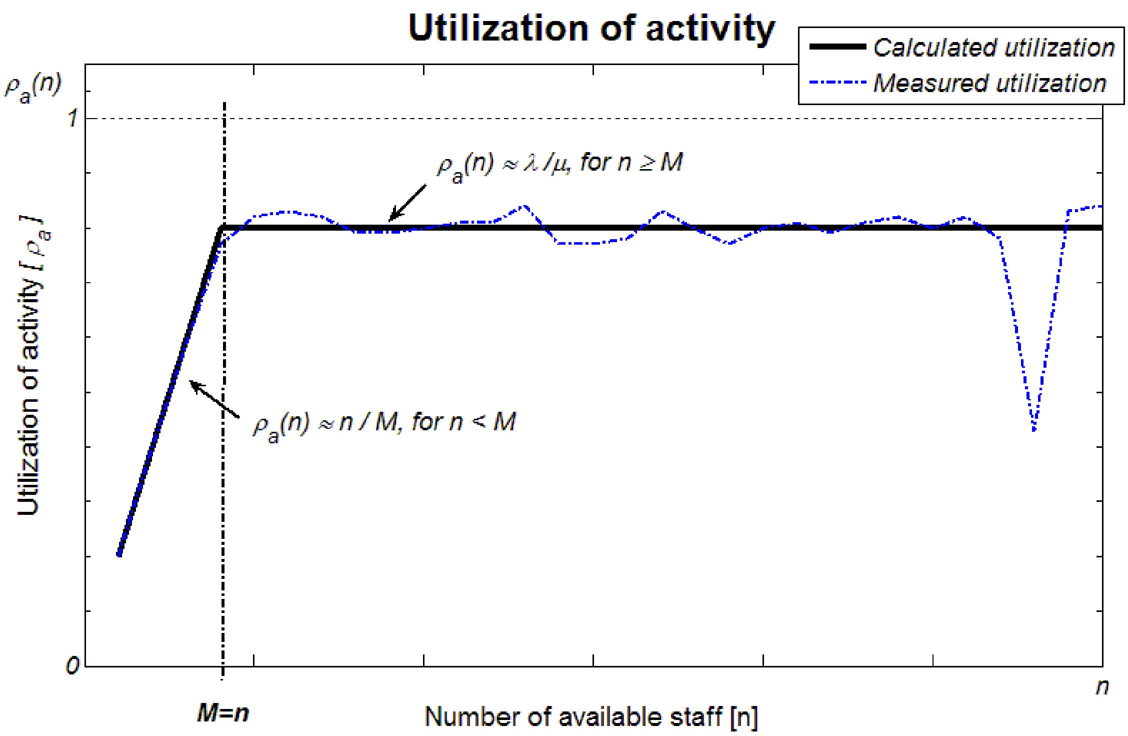


Figure 4.12: The simulation result (dotted line) and the estimated calculated model (solid line) for the activity utilisation $\rho_a(n)$, which is a component of the overall utilisation $\rho(n)$.

The results of the simulation experiments for a specific interarrival time t are illustrated in the dotted line. It is obvious that even though the statistical randomness has caused some deviations, a trend is observable. In order to describe the trend, the components of the overall utilisation should be considered. The overall utilisation $\rho(n)$ is a combination of the utilisation of staff $\rho_n(n)$ and the utilisation of the tasks themselves $\rho_a(n)$, here expressed as activity in order to emphasise that it is an exceptional process which depends on the participating staff member. Figure 4.12 illustrates the component for the utilisation of the activity $\rho_a(n)$.

The dotted line displays average utilisation $\rho_a(n)$ of the activities. A linear trend is observable for the understaffed condition where fewer staff (n) are available for tasks (M). In the case of understaffing $(n < M)$, some activities remain idle waiting for staff. Therefore, the utilisation $\rho_a(n)$ is limited to the number of available staff in the understaffed condition. Whereas in an overstaffed condition $(n \geq M)$, a surplus of staff causes a permanent utilisation for the activity which is then only limited to the ratio of the arrival rate λ and the service time μ. These observations can be summarised in the following equation, which calculates the utilisation of the activity as:

$$\rho_a(n) = \begin{cases} \dfrac{n}{M}, & \text{for } \dfrac{n}{M} \leq \dfrac{\lambda}{\mu} \text{ and } n \leq M \\ \\ \dfrac{\lambda}{\mu}, & \text{for } \dfrac{n}{M} > \dfrac{\lambda}{\mu} \text{ and } n > M \end{cases} \tag{4.2}$$

Equation 4.2 is valid for $\lambda \leq \mu$ otherwise the utilisation would be equal to 1, which indicates an instable condition and causes longer queues (Law & Kelton 2000). The term $\frac{n}{M} \leq \frac{\lambda}{\mu}$ limits the utilisation to the ratio of arrival time to service time in case the staff to process ratio is of larger value. The upper part of the equation 4.2 addresses the condition of understaffing, whereas the lower part expresses the condition of overstaffing, which depends on the arrival time to service time ratio, where the activities are saturated with staff. Once equation 4.2 is elaborated in order to consider the interarrival time, λ is substituted by $\frac{1}{T}$ and the utilisation of activity $\rho_a(n)$ can therefore be written as:

$$\rho_a(n,T) = \begin{cases} \dfrac{n}{M}, & \text{for } \dfrac{n}{M} \leq \dfrac{\lambda}{\mu T} \text{ and } n \leq M \\ \\ \dfrac{\lambda}{\mu T}, & \text{for } \dfrac{n}{M} > \dfrac{\lambda}{\mu T} \text{ and } n > M \end{cases} \tag{4.3}$$

Utilisation of activities $\rho_a(n,T)$ in dependence of interarrival time T and the number of staff, is shown in Figure 4.13. The threshold between over- and understaffing can easily be observed.

The utilisation of staff $\rho_s(n)$ is the other component that is included in the overall utilisation of the flexible workload environment $\rho(n)$ (Figure 4.11). Figure 4.14 is directly obtained from the simulation, measuring the utilisation of staff being outside of the resource pool.

The measurement (Figure 4.14) shows that the utilisation of staff is independent

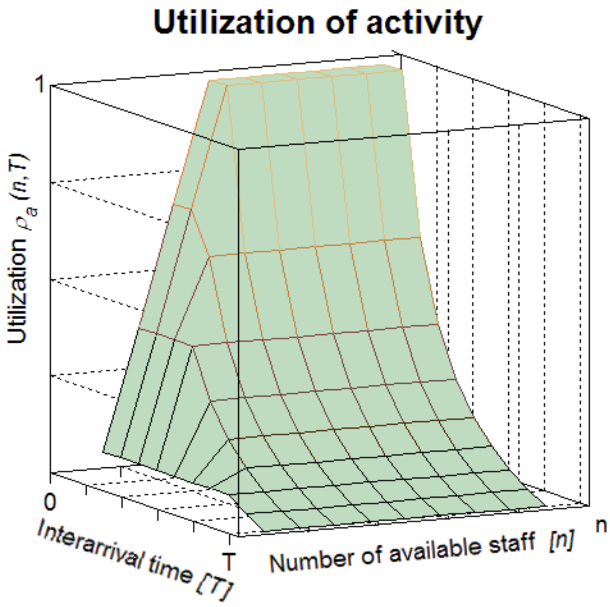


Figure 4.13: Graphical representation of equation 4.13, which illustrates the activity utilisation $\rho_a(n, T)$ in dependence of interarrival time T and number of available staff n.

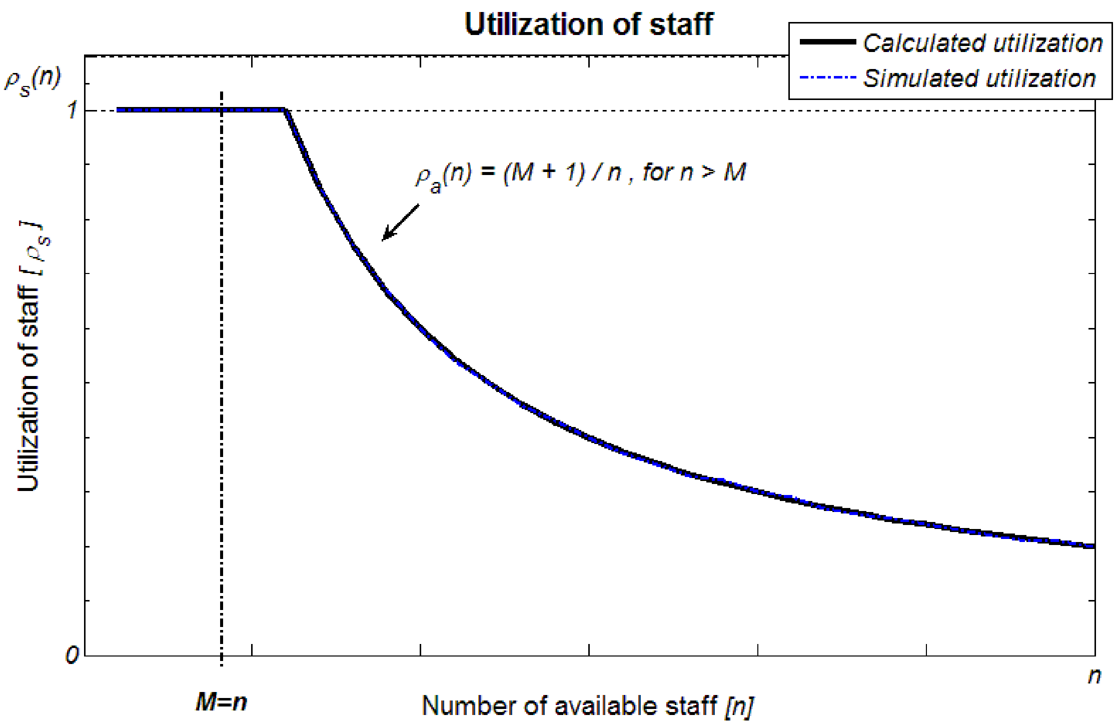


Figure 4.14: The simulation result (dotted line) and the estimated calculated model (solid line) for the staff utilisation $\rho_a(n)$ for a specific arrival time t in dependence of the available staff n.

of the arrival time λ and of the service time μ, because the simulation result (dotted line) is equivalent to the estimated calculated utilisation of staff (solid line). It can be seen that in cases of understaffing ($n < M$) the utilisation of staff is equal to 1. This indicates that the staff are fully occupied with a high workload. In the case of staff number being equal to the number of tasks ($n = M$), staff will not be interrupted or alternated between tasks. Once the process chain is overstaffed ($n \geq M + 1$), the workload is decreased by every additional staff member. This relationship is summarised as a function for the utilisation of staff:

$$\rho_s(n) = \begin{cases} 1, & \text{for } n \leq M \\ \dfrac{M+1}{n}, & \text{for } n > M \end{cases} \tag{4.4}$$

Equation 4.4 is valid for all λ as the utilisation is directly obtained from simulation model results. Having derived the mathematical expressions for both components (4.2) and (4.4). The overall utilisation $\rho(n)$, displayed in the graph of Figure 4.12 can be calculated by multiplying the utilisation of staff with the utilisation of activities:

$$\rho(n) = \rho_s(n) * \rho_a(n) \tag{4.5}$$

This delivers the black line in Figure 4.12, that is equivalent to the observed trend, which has initially been presumed. The equation in (4.5) can easily be extended to incorporate the interarrival time by considering equations (4.3) and (4.4):

$$\rho(n, T) = \rho_s(n, T) * \rho_a(n, T) \tag{4.6}$$

Calculating the resulting utilisation $\rho(n, T)$ according to equation 4.6 delivers the graph displayed in Figure 4.15.

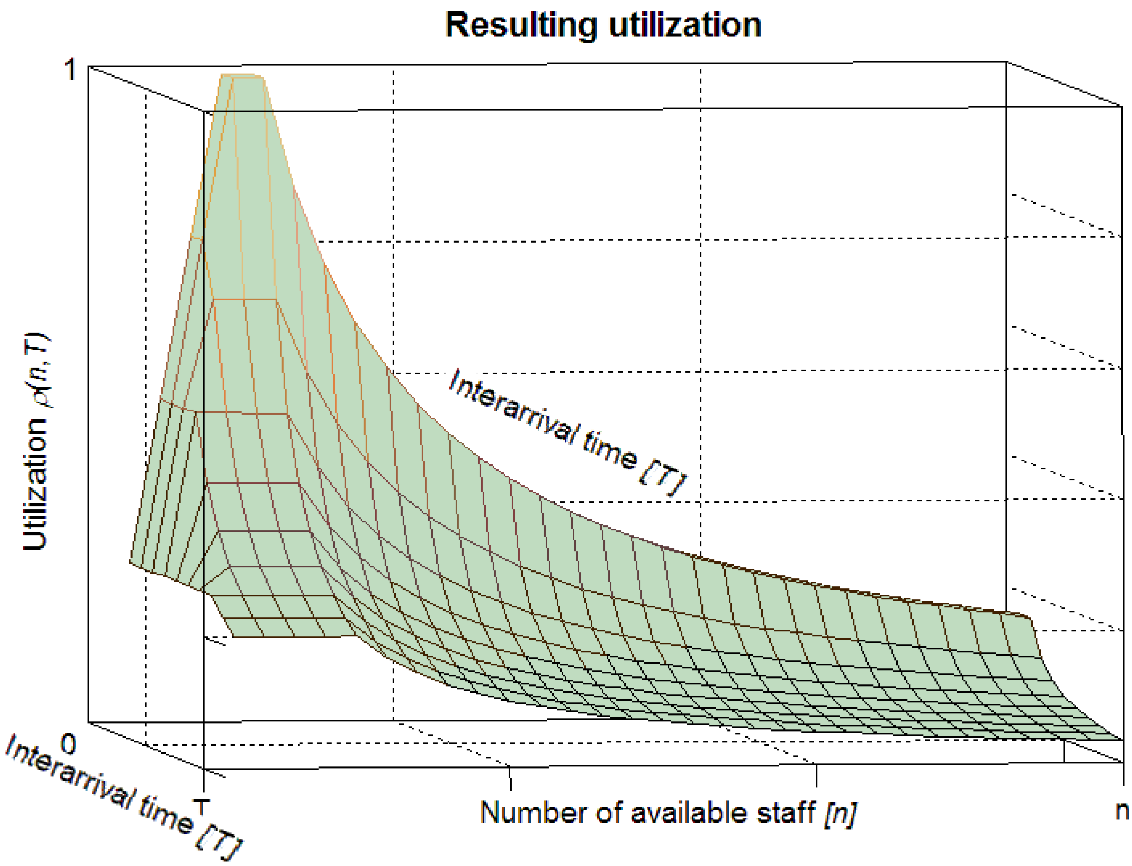


Figure 4.15: Calculated utilisation $\rho(n,T)$ according to the mathematical expression (4.6) considering the utilisation of staff $\rho_s(n)$ and activity $\rho_a(n)$.

Comparing Figure 4.15 with Figure 4.10, it is obvious that the differences are ultimately due to the variability caused by random arrival rates. By assuming constant arrival rate and constant service rate, the utilisation plot contains no fuzziness (Figure 4.15). This can be modified by incorporating the corresponding statistical distributions for the arrival time λ and the service time μ in equations (4.3) and (4.4).

4.3.2 Results Analysis

Although an insignificant variation is shown due to the variance of the patient arrival time and service time, a pattern can be obtained which is hence described in equation (4.6) with the considerations of its components in equations (4.3) and (4.4). In reference to equation (4.6), outcomes showed similarities with the initial measurements (Figure 4.15) where the hyperbola axis are defined by the interarrival

T and the number of available staff n (Figure 4.14). The plateau marks the area where $\rho(n, T) = 1$ with the interarrival time set at $T \leq \mu$ and the number of available staff is less or equal to the number of tasks ($n \leq M$). The slope on the left side of the plateau ($n < M$) marks the area where the system tends to become unstable. The two graphs showed that high utilisation conditions are likely to happen when the available staff number n is less or equal the number of tasks M, and the arrival time is less than the service time. To avoid high utilisation, the service time should either be less than the arrival time or an excess number of staff should be employed. As service times are rarely manipulable in healthcare, it is important to consider the number of staff as a variable.

4.3.3 Discussion on FRA

Equation (4.6) represents the utilisation of staff who are working in a flexible workload environment. The area of high utilisation is easily obtained due to the mathematical description ($\rho(n, T) = 1$) as shown in Figure 4.15. This formula shows that the system in this critical area tends to become unstable and long queues are likely to develop. High utilisation is also a reason for an increased error rate which should be prevented especially in critical environments such as healthcare. The following example in Figure 4.16 shows how to avoid severe staffing conditions: assume the number of tasks within a process chain is $M = 5$ and interarrival time is $T = 1.1h$. As mentioned earlier and based on real observations; the error rate increases dramatically at an overall utilisation level of 85% within our assumed example. Therefore the function should not exceed 85% and that is guaranteed at a staffing level of $n \geq 7$. This example shows that the proposed model can be used to determine the optimum number of staff to achieve the required utilisation, taking into account the uncertainty of the arrival rate λ. Decision makers can also use the model to justify the required number of staff in order to obtain quality service along with an acceptable utilisation level of their staff.

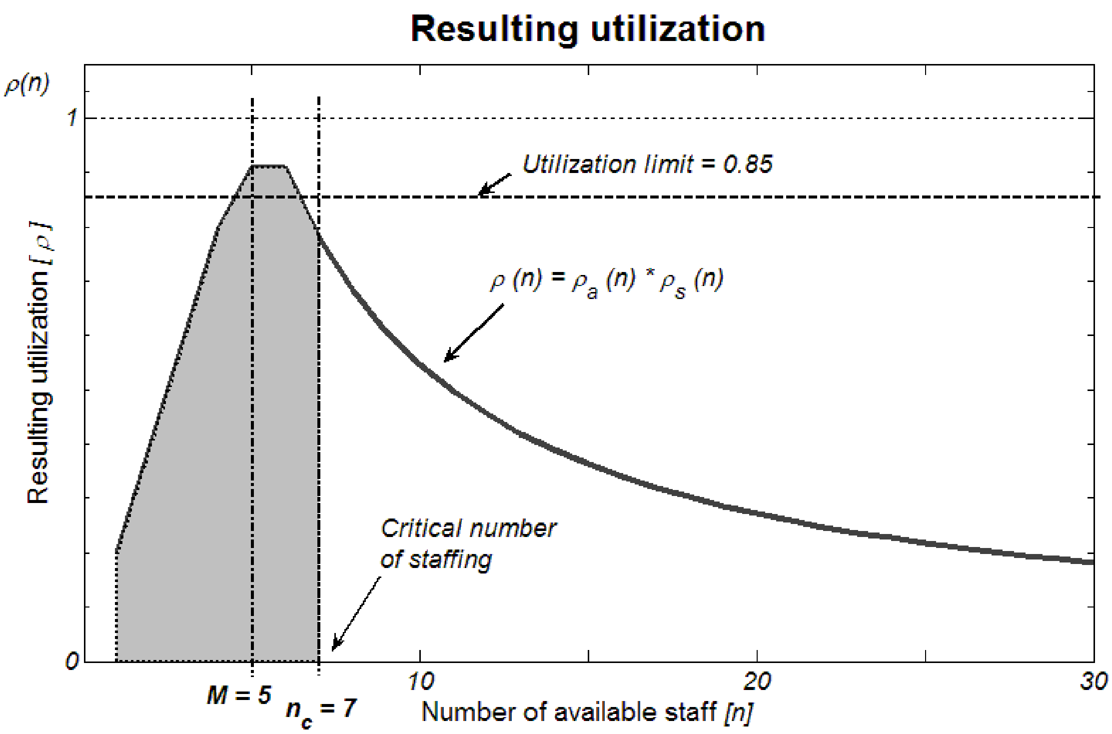


Figure 4.16: Example to determine the critical number of staff n_c for $M = 5$ processes with the utilisation limit of $\rho = 85$ per cent.

It is worth mentioning that the system will certainly be maintained with less numbers of staff under one condition – interarrival time must be smaller than the service rate $T \leq \mu$. Since this condition is impossible to control, optimising number of staff is needed. The above example illustrates guidance for decision makers attempting to investigate the workload that will lead to an instable queuing system. Patients arrival times can be described as a Poisson distribution (Isken et al. 1999) and therefore the manager can use the simulation model to examine the impact of changing the interarrival times and other sources of variability. It is also worth noting that the studied model considered one type of skill set (i.e. nurses). However, in real-life, a skill set mix would be required (i.e. doctors, consultants, administrative personnel) to complete the care pathway of patients through their treatment journey (Harper et al. 2009). Another important issue to be considered is the fact that the service rates within a process chain differ based on its nature. In this proposed process chain (Figure 4.9), it is obvious that the longest service rate of one particular task slows down the other processes and internal queues are likely to build up in front of the slowest server (bottleneck stage). The limitations addressed here are of current research and the presented model will be extended adequately to analyse this issue.

Despite these two limitations in the model, decision makers can use the model to achieve a greater transparency to the system operating conditions which eventually leads to a better understanding of the nature of such a flexible workload environment on staff utilisation. For such work environments where a high quality standard is crucial, decision makers can decide more accurately on the number of staff needed to maintain the service level and avoid the unstable conditions. Considering the case of the Canadian nurses in 1999 with 16 million lost nursing hours, it is clear that an increase in staff number might avoid negative consequences such as; error rate and significant amount of sick leave due to burnout. If a reduction of just 5% of sick leave could be achieved by considering a well adjusted utilisation rate among nurses, this would probably save costs equivalent to the annual salary of 4,000 employed nurses.

4.3.4 Queuing Theory Consideration

Identifying the correct number of staff within a process is generally an important issue, especially in highly fluctuating demand applications such as emergency departments. It is not only crucial and imperative for the quality of service, but is also a cost driver. An understaffed emergency department can develop serious unwanted consequences such as; high error rate, stress among the healthcare personnel, and burnouts which can lead to unplanned absenteeism. Spontaneous absenteeism inflicts even more stress on personnel and additionally lowers the morale among the remaining staff. To avoid these negative outcomes, it is important to identify under which conditions these effects can be obviated. Unstable queuing systems are conditions in which staff are highly utilised and queues for services are increasing. Indicators which show a higher mortality rate during high occupational periods (Richardson 2006, Unruh et al. 2007) give reasons for concern and emphasise the need for a properly adjusted staffing of the process chains.

In order to describe and understand the mechanism of a dynamic process chain the authors derived a detailed simulation model of a larger emergency department in one of the university hospitals in Dublin. This model allowed the authors to investigate the dependencies of staff utilisation in accordance with the number of staff and the patient arrival time which are then described in equation (4.5) under the consideration of the constraints in equation (4.3) and (4.4). These equations emulate the dynamics in such a changing work environment by simulating flexible workload management. Results show that two conditions should be avoided; first, the longest service rate within a process chain should not exceed the arrival time ratio. Secondly, staffing must not be lower than or equal to, the amount of tasks within a process. If these two conditions are not met, the system will be described as an unstable system resulting in long queues and high utilisation of staff. A challenge to decision makers will always be; how to develop a certain balance to maintain satisfactory service quality and avoid staff over utilisation. The model developed aims to offer a decision support tool to decision makers by providing insights on staff utilisation under different work schedules.

During the design of a healthcare unit one should bear in mind that providing healthcare is not producing health. Healthcare personnel have an obligation to their patients, who have human needs and have no patience for stop watches whilst they are waiting to be seen. Providing healthcare personnel with such freedom to care for their patients enables a threefold winning situation: the patient receives better care and advice, stress among personnel is reduced as well as unexpected absenteeism. Thus the negative effects of absenteeism can also be lowered such as costs and lower quality of care. Avoiding stressful working conditions is therefore a worthwhile investment.

4.4 Summary on Framework for Flexible Resource Allocation

The above framework allows the mapping and reproduction of the concept of secondary pathways in simulation models, which can be observed in servicescape. As this concept covers flexible resource allocation and a flexible routing of those resources, it presents a high barrier to the simulation modeller as the complexity of this concept involves a significant amount of administrative and maintaining effort during the model construction process. In order to lower this additional complexity, this framework provides guidance and instructions which help the modeller to design a code block that automatically generates a simulation module involving FRA, which is hence prepared to apply the concept of secondary pathways into the simulation model.

In general, the framework explains which environment the FRA can be applied. Thus far, servicescape has been identified as a potential application field for this simulation mapping concept, but there might be other potential unidentified sectors which may benefit from its application. After identifying the right environment, the modeller must identify the right tool – for that reason the requirements of the simulation software package are listed. A brief summary regarding the data requirements is also provided, as the consideration of two separate pathways may require quantitative and qualitative data in order to retrieve reliable information.

As previously indicated, data is the most important part of the model, having a major impact on the quality of the model and for the accuracy of the model. In this chapter this importance is highlighted and the special requirements or considerations for the application of the FRA framework under the concept of secondary pathways as they are explained here. Furthermore it is also detailed how the simulation research methodology is supplemented so that the application of FRA produces trustworthy results.

The core contribution of the framework is to provide guidance and an instruction set in order to equip the simulation modeller with the ability to replicate FRA as for example within the need to map secondary pathways. This instruction is provided by explaining how FRA is set up and additionally to provide an algorithm with which the modeller is facilitated to program an automatically executable simulation mapping. This automated mapping delivers two advantages: first, the effort to build such a complex routed model is reduced and second, the possibility of accidently inserting errors can be minimised. However, additional effort must still be invested as the newly created simulation module requires some adjustments to the remaining simulation environment. These adjustments consist of connecting the pathways with the entrances and exits, as well as defining the data retrieval / measurement points.

The last sub chapter considers the aspects which are essential in the world outside of the model with regard to data retrieval in respect of the special requirements for the FRA framework. One of the special requirements is that it should be regarded whether and how the concept of secondary pathways is applied. This impacts the data retrieval strategies. The same considerations apply to verification and validation, but in general, with few special exceptions, the strategies described in the third chapter are equally applicable.

With the guidelines and instructions provided here, FRA enables the simulation modeller to enhance his / her simulation models to reproduce a higher degree of accuracy for servicescape environments. Complexity of models is a common concern, but as soon as such dynamic and flexible routing is not tailored by the modeller anymore, the effort and errors which come along a higher complexity degree, are hence reduced. Experienced modellers are designing their FRA-block in accordance with the algorithm described above, but under the consideration of reusability. With this measure, future FRA models are as easily built and maintained as common process flow models.

The first person who benefits from this framework is the modeller. However, as the model displays the routings and the work flow of the investigated system with a higher precision, the decision maker retrieves additional information. Transparency should however be considered and be provided by the modeller who can achieve this by including a GUI which delivers relevant KPIs, some animation and parameter fields where scenarios can be tested. With these measures the concept of secondary pathways becomes transparent and illustrative for decision makers who have retrieved a better understanding of the system and can make better decisions regarding improvements. The decision maker is gaining a holistic perspective onto dynamic systems that are yielding multiple process pathways of which its resources are interactively connected. This holistic perspective hence leads to a sound decision basis for improvement measures.

Chapter 5

St. Vincent University Hospital Model

The actual field work is used to illustrate the validity of the Flexible Resource Allocation (FRA) modelling concept. The field work is carried out in the emergency department (ED) of a large academic teaching hospital, here referred to as the St. Vincent University Hospital (SVUH). The purpose of the field work has two objective types: the first one is an academic objective, which had the motivation to show, that a higher degree of detailed modelling can be achieved by using a structured approach such as the FRA concept. The *clinical* objectives have hence been to identify three issues within the ED. The first *clinical* objective is to investigate the process flow within the ED and explain unexpected queues, and also to provide a tool which allows measuring certain key performance indicators (KPIs). The second *clinical* objective is to identify the documentation time of the medical staff, as many staff members complained, that they felt that they spent more time documenting rather than with the patient. The third *clinical* objective is to optimise the staffing setup and distribution within the ED. The motivation behind finding an optimised setting for the ED is to find an answer to the question of whether the current ED is able to meet the 6 hour Length of Stay (LoS)- target provided by the HSE. These *clinical* objectives were negotiated with the management of the ED who were especially interested in the outcome of the *clinical* objectives. The academic objectives were triggered by the motivation gained from the literature research, which indicated that research in the area of complex modelling is overdue.

5.1 Introduction

The structured FRA concept required practice tests to evaluate whether it would be applicable as a recommended modelling technique. The best way to prove a concept is by putting this concept into practice. As the data collection phase within the ED of SVUH indicated high dynamics and flexibility among the allocated resources, it appeared to be an ideal proofing field. After a detailed investigation and consideration of the required resources, the FRA concept is applied with the consideration of MPPM.

5.2 Description of SVUH Emergency Department

The ED is situated within the St. Vincent University Hospital (SVUH) and shares resources such as diagnostic radiology and the laboratory, where blood tests are diagnosed. There are three main patient groups which are seen in the ED: self referred walk-in patients, transferred patients with a letter from the GP, and acute patients delivered by an ambulance. The ED accepts all patients, and provides immediate treatment for almost all kinds of injuries and complaints. Only few exceptional cases are not treated, such as burns, paediatrics or mental illnesses. Those patients are transferred to an appropriate hospital. Patients are classified by their severity into triage groups and into complaint groups (ICD-10 had not been used for classification at that time). These complaint groups indicate the certain pathway for the patient through the ED. The patients who are successfully treated and require no follow up treatment are directly sent home. Those that require follow up treatment are either sent to a general practitioner or are transferred to a different specialty unit either within the SVUH or a different hospital. Patients are also transferred into the SVUH directly; the SVUH has limited capacity which results in long waiting queues between the ED and the SVUH. As the capacity of the ED is limited, many patients had to wait in the corridor, placed on mobile beds, named as trolleys. The

ED shares the diagnostic radiology with the SVUH of which there are three x-ray diagnostics and one CT diagnostic device. The laboratory is facilitated for blood and urine tests and is connected via pneumatic delivery.

5.2.1 Purpose of the Emergency Department

The general function of the ED is to supply immediate urgent care for all accepted patients. In the overall context, including the perspective of the hospital, the ED functions as a gate keeper for the provision of care. Patient arrival must be planned by the hospital due to limited bed and treatment capacity. The ED can therefore be regarded as a buffer which reduces the high uncertain patient arrival by selection and provision of first acute treatment.

From the perspective of the patient, the ED is an additional health care facility where immediate care can be provided even in cases where a GP is not available. In the Irish context, the ED is a supplement to the available healthcare infrastructure. Patients are still treated even though they are not an emergency case, as the name might implicate. Annually, around 45,000 patients go through the ED with approximately 50 different patients groups, which averages to 3,750 patients each month. Patient demand is highest on working days, whereas the demand is at its lowest over the weekend (Figure 5.1 on Page 209).

Treatment is provided for all patient cases with the exception of burns, paediatrics, and mental illnesses. Those exceptional cases are diverted to specialised units of different Dublin hospitals; in severe cases, first aid is of course provided. All other patients are admitted to the ED and are treated according to their complaints with the best treatment possible given the facility. In general, the treatment is divided into three different main groups which are located in three separate units within the ED. The first unit is named as the ”chest pain” unit which is dedicated to patients who have either a lung or a heart problem. This unit is equipped similarly to an

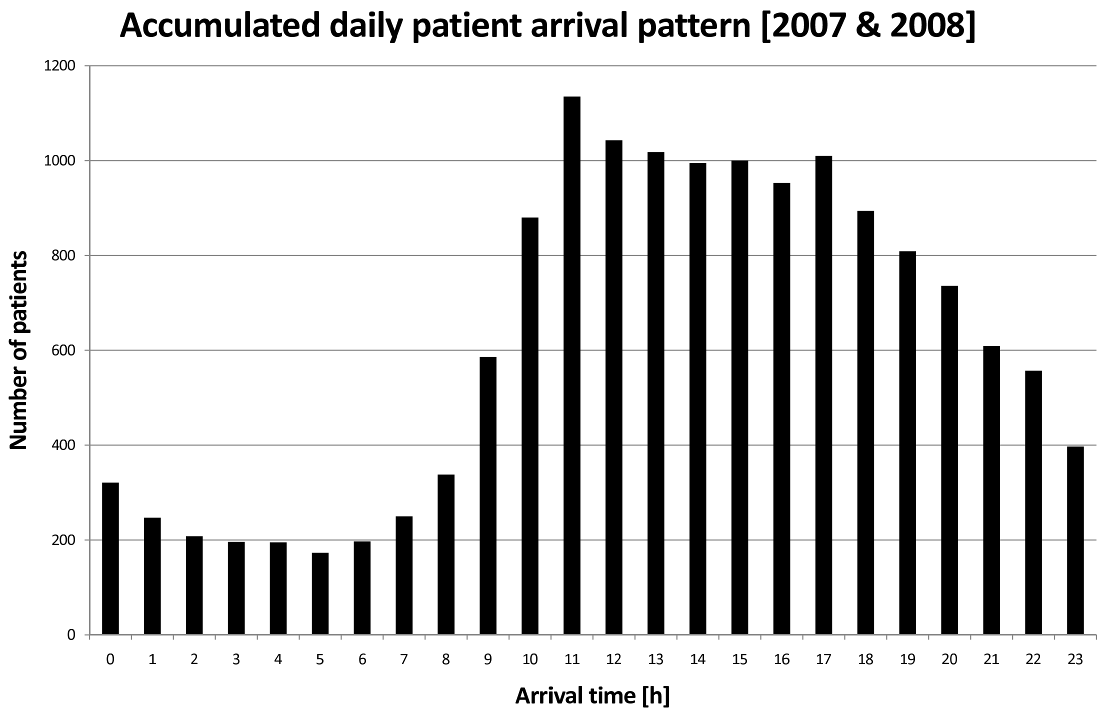


Figure 5.1: Daily accumulated patient arrival distributed over one day per hour. The patient arrival of year 2007 and 2008 until October is accumulated and displayed here.

intensive care unit (ICU) which holds cardiovascular monitoring, provides artificial respiration, syringe drivers and offers infusions. Those patients requiring special attention within this unit are located in an isolated section of the ED. The third unit is called the "Minor" unit and is dedicated to patients who require orthopaedic care and treatment. Such cases are for example fractures, displacements, or wounds that require treatment. The second unit is a general unit which covers all other patients requiring treatment.

5.2.2 Patient Pathway Description

The most common patient pathway in the ED is displayed as follows: patients must first register before they enter the ED. They are then asked to wait in the waiting room until they are triaged by a triage nurse or doctor. These doctors and nurses are shared resources among the ED and classify the severity of the patient according to the Manchester Triage Group (Mackway-Jones et al. 2006). Following this, depending on their severity they either continue to wait in the waiting room or are sent directly to one of the three units. After being interviewed, diagnosed and treated in the units, the patients are either sent home, referred to a GP or specialty unit of a different hospital (outpatient clinic), or are admitted to the hospital. Patients do die in the ED, but this is not a common occurrence. Potential hospital patients are monitored by the clinical decision unit (CDU) which has the final decision on whether a patient requires hospital treatment. The CDU is functionally placed among the ED and the SVUH, even though the patients remain in their units. The main pathway is illustrated in the Figure 5.2 which groups all 50 patient groups together in one flow.

In addition to the common route, there are also alternative routes within the ED. An example is when the patient arrives via an ambulance. In this case the patient is immediately delivered to the according unit. Registration and triage is either done while the patient is in the ambulance or later in the unit. A further alternation would be a patient who is waiting aborts his / her wait and simply leaves the ED. A more extreme version of this can occur when the patient aborts the treatment in the middle of the ED visit. This spontaneous quitting is noted in the hospital records with the abbreviation DNW which stands for: did not wait. Another alternation which is not very common, would be that of a patient, who is highly confused and disturbed by the noise and stress of the ED, being placed in a quiet room instead of a normal room or a cubicle. These alternations are considered in the simulation model in order to deliver an accurate and precise picture of the ED. Figure 5.2 illustrates the higher detail levelled process flow map, including the alternative routes. A process flow considering all possible patient groups is mapped in section 4.4 on page 171 where the qualitative data retrieval is evaluated.

Within the units, patients are placed either in separate rooms or in cubicles which provide privacy in the form of a curtain. The patients are generally placed on mobile beds in the chest pain unit and in the general unit but not in the third unit, where the patients are optionally placed on a chair. In case of high demand, when

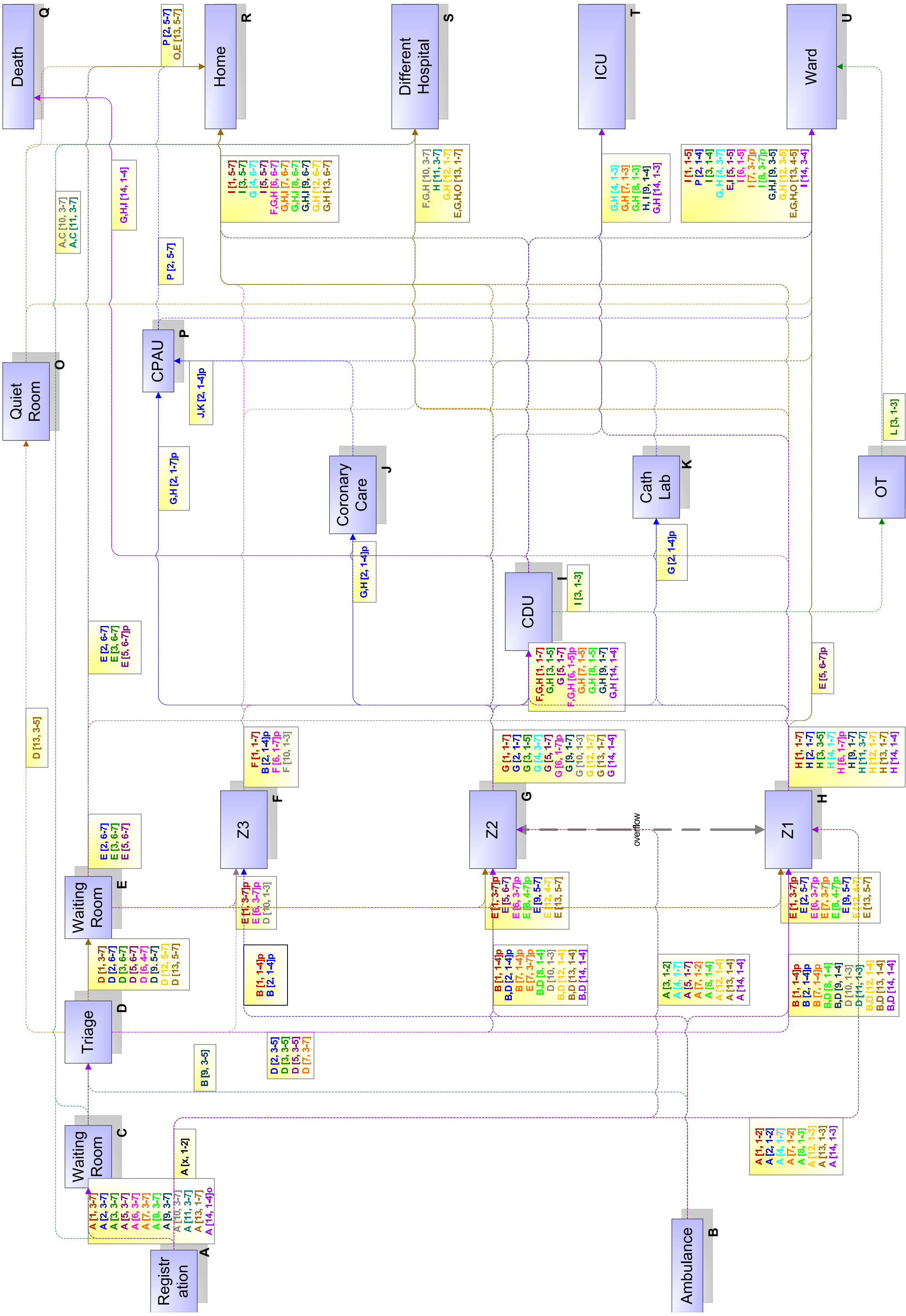


Figure 5.2: Flow chart representing all major 14 patient routes, where the legend on each arrow indicates the complaint route, triage level and destination.

the capacity limit of 23 patients is reached, patients are placed in the corridor on their mobile bed. In addition, patients waiting in the corridor will often be awaiting admittance.

The *pathway within the pathway* is divided into several steps that depend on the complaint and on the treatment the patient requires. However, a certain pattern can be observed for all units: first the cubicles or rooms require cleaning and disinfecting by the cleaners. Then the patient is brought to his / her bed with the aid of nurses and with the assistance of porters. A doctor then interviews the patient while a nurse takes any required blood samples. After the interview, the patient is transported to diagnostics by a porter if no immediate indicator for the correct treatment can be found. The diagnostic commonly takes place in the medical imaging unit. There, the patient is scanned either via x-ray or CT. The patient is then delivered back to his / her cubicle. Consultation is then followed with the findings of the diagnosis by either a doctor, senior doctor or a consultant. Following this, the appropriate treatment may begin if applicable. The procedure with the patient concludes with the preparation for release, which means that instructions for further treatment either at home or by a GP are provided. The last step is the cleaning of the cubicle, which does not involve the patient directly. This procedural pattern can be similarly observed in all three units, whereas treatment details differ according to the patient group.

5.2.3 Administrational Setting

The majority of administration is done from a central desk where three staff members coordinate with patients and staff. One of their tasks is to check whether capacity is available in case an ambulance team requests admittance for their patient. In cases where the capacity limit is reached, they check with different EDs in the area. Another task is to coordinate the hospital admittance and the correct administration of the patient data. Another administrational task is the assignment of staff to their according shifts by accessing an external nurse pool which can be utilised in high demand phases.

5.2.4 Staff Types

The following staff types are available in the ED: medical staff, supportive staff, and administrational staff. The medical staff comprises consultants, pharmacists, physiotherapists, radiographer, and nurses. The supportive staff is represented by porters, receptionists, medical social workers and by cleaners. Cleaners and porters are dedicated to all units within the ED, whereas doctors, senior doctors and nurses are either directly dedicated to a certain unit or are committed to all units within the ED. Different staff members have different skill sets and different duties and therefore provide a different form of service. Nurses for example provide general care and assistant treatment, while doctors are responsible for treatment, with the aid of nurses. Consultants, however, are advise doctors in difficult cases and in general are not directly involved with treatment.

Patient data is documented by all staff types except porters and cleaners. There are two types of documentation, the first is the mobile patient record file, which is stored in a container and holds all patients records. A staff member who treats a certain patient will first access this and take it along to the patient, where the file is updated. A secondary record is kept via computers which are connected to the HIS. The staff member must update this file once the treatment is finished with the notes taken on the patient record file. Staff members are advised to update the HIS as soon as possible, but at times with high patient demand, it has been observed that several patient file records are processed at a time.

5.2.5 Interfaces of the Emergency Department

In order to reflect the above described ED in a simulation model, data must be collected from the ED. This can be done by obtaining access to hospital records which provide the necessary patient data, or by interviewing staff, and / or through observation. An insight into the quality of the three sources has already been discussed in section 3.3.2 on page 121. Redundancy of information is highly desirable, if not recommendable. This is because flaws in one data source, such as technical outliers in the quantitative data, can be more easily identified and better considered than if there was only one source, which had to be regarded as the unquestionable truth. As discussed in the second chapter on different research methodologies, the various forms of redundant information differ in their quality due to the different perspective angle, but supplement each other by considering the advantages of each approach. The mixed method approach aligns the quantitative and the qualitative research methods and is supplemented by the scientific research methodology; thus creating a complete picture of the system under investigation.

5.3 Data Mining

For the purpose to build a simulation model that represents FRA and MPPM, the data is prepared as described in the Section 3.3.3 on Page 128. To ease and fasten the process of data retrieval, processing and conditioning, a data mining module is created which is in detail laid out in the Section 4.1.3 on Page 158 and on the attached DVD. The data provided is kept anonymous, but the essential information about the routing, processing and timing of the patient can still be retrieved.

Data Mining Module

The Data-Mining-Module (DMM) is a combination of further sub modules with different tasks. The DMM is structured in separate sections that are also represented in separate modules:

1. *Preparation* – identify outliers and deliver a set of data with complete patient

property fields and without any erroneous time stamps. This data set is then tagged as trustful;

2. *Conditioning Data* – compare the trustful set with the original data set and eliminate outliers;

3. *Grouping Data* – according to the entities in the categories, groups are generated;

4. *Retrieve Statistical Properties* – statistical properties, frequencies and ratios are calculated and displayed in spreadsheets;

5. *Plot Data* – generates plots from the previous sections in separate spreadsheets.

The DMM is programmed in a way that it can be reused whenever the patient data is presented in a table arranged manner. The number of categories is not limited specifically unless the number of available columns in a spreadsheet is not exceeded. This feature also applies to the number of groups which is also only limited to either the maximum number of rows available in a sheet or the number of maximum sheets which is bound to the amount of available memory. The configuration is made by adjusting the global variables which are placed on top of the main module – a comment on each line helps the user to apply the right adjustments. The main module executes all separate modules in a procedural style; it therefore unites the other modules to a whole sub routine. To execute the sub routine, it must be embedded in the spreadsheet calculation workbook which contains the hospital data.

Preparation The data is prepared by retrieving the durations: for each time stamp available, the difference is calculated and associated with the according process. The time difference reflects the actual process times. In order to test for outliers, the process times are summed and compared with other time differences. The hospital provided time stamps from which the whole process time for waiting for treatment could be retrieved. Also available were sub process times, such as waiting in the waiting room and triage time. Comparing the process time with the sum of the sub process times created a basis for decision, whether the data presented here is trustworthy. A tolerance range of 15% is granted for this comparison. The new trustful data set is hence generated by selecting only those patients whose summed process times do not differ more that 15% from the whole time difference and where all properties fields are filled in. In the case for the last ten months of the data set, only 9,029 patients out of 35,410 are valid and considered as trustworthy.

Conditioning Data For data conditioning, the maximum and the minimum were obtained from the trustworthy data and patient data which exceeded the maximum and the minimum is deleted from the original data set. Due to the above described criteria, 2,983 patient data sets are identified as outliers, which is 8.4% of the original amount for the year 2008. The data sets without the outliers, 32,427 in total, are here referred to as "cleaned data" and used for further evaluation.

Grouping Data The data is grouped according to the three categories that are provided initially by the hospital. The first category is the patient complaint, the second the specialty which treated the patient and the third is the category of the referral type. In order to retrieve the size of each category the data is scanned for the amount of different entities. For example in 2008 there are 49 complaint groups, 18 specialty groups and 26 referral groups. These groups are listed on a separate spreadsheet and indexed with the resulting new sheet, which is generated in the 'Retrieve statistical properties' sub module in the next step. This index provides easy access to the desired sheets and eases the handling of the resulting data.

Retrieve Statistical Properties After all the necessary preparation is completed, the retrieval of the statistical properties required for the building of the executable model can be initiated. The DMM delivers more data than is necessary, but as additional effort is minimal, it is worth having an excess amount of data.

For all the data and also for the grouped data, the following statistical properties were calculated and displayed on a separate sheet named with a prefix which is taken from the first letter of the category (C for *complaint*, S for *specialty*, and R for *referral*). A subsequent letter G is set in case it is a sheet which contains graphs, the next prefix is a letter from a to d which indicates the number of graph sheets used, another subsequent prefix which is a running number (necessary to address the sheet) and finally the first nine digits of the group name. The sheet name is set up as

```
<First category letter><|G|>|(|<|letter for graph index|>|)|<Index
    number generated by DMM>_<Group name>
```

Listing 5.1: Declaration and definition of the Sheet Names

where the <> indicate fields and || indicate optional dependencies on certain cases.

The statistical properties are on the first group sheet displayed in the tables which show:

- Main table showing the process stages rows:
  - Interarrival Time;
  - Wait for Triage;
  - Wait for Treatment;
  - Time in Waiting Room;
  - Treatment Time1;
  - Treatment Time2;
  - Wait for Admittance;
  - Total Time;
- Main table displaying the durations and counts in the columns:

  - Count;
  - Minimum;
  - Maximum;
  - Average;
  - Standard Deviation;
  - Variance;
  - First Quartile;
  - Median;
  - Third Quartile;
  - Inter Quartile Range;
  - Number of maximum arrivals at a certain time index (retrieved from histogram);
  - Time index of the maximum arrival (retrieved from histogram).

- Further frequency tables that display the arrival pattern:
  - Frequencies grouped by the time of day;
  - Frequencies grouped by the time of day for each weekday;
  - Frequencies grouped by weekday;
  - Frequencies grouped by month;
  - Frequencies grouped by the weekday for each month;

The name of this sheet is *<First category letter><Index number generated by DMM><Group name>* which is in the case of Chest Pain: **C8_Chest Pain**.

Plot Data The following sheet displays graphs which use the data in the frequency tables from the previous sheet. These graphs are useful in order to display the arrival pattern and to validate those with the reports provided by the hospital. Five graphs are displayed in Figure 5.3:

- Frequencies grouped by the time of day
- Frequencies grouped by the time of day for each weekday
- Frequencies grouped by weekday
- Frequencies grouped by Month
- Frequencies grouped by the Weekday for each month

These sheets are named according to the naming pattern of (a) which would result in the case of Chest Pain as **CG(a)_Chest Pain**.

The patient arrival data is obtained from the registration time for each group and displayed in histograms. Typical arrival patterns are displayed in Figure 3.7. The top left histogram displays the weekly arrival pattern where the arrival is cumulated for each day. The top right accumulates the monthly arrival pattern cumulating each month of a year whilst the bottom right displays the arrival pattern throughout a day, separated into hours, and the bottom left indicates the grouped annual arrival pattern where the weekdays are accumulated for each month. The most important arrival patterns are the weekly arrival and the daily arrival patterns, which are set to adjust to the staff shifts. The daily arrival pattern shows clearly that the demand in between 0 and 8 is just 15% of the rest of the day. Staffing level can be adjusted accordingly to such findings.

The next sheet contains intermediary results of the retrieval of the process histograms; the frequency tables for each average process time in the row of the main table are provided. At least 200 predefined bins are provided in the standard setting in order to achieve a high resolution for the distribution; in cases where the difference between the minimum and the maximum is smaller than the predefined slot size, the bin size is set to 1; whereas in other cases the slot size is a constant ration between the difference and the predefined bin number (rounded to the nearest integer). The sheets containing these tables are named according to the naming

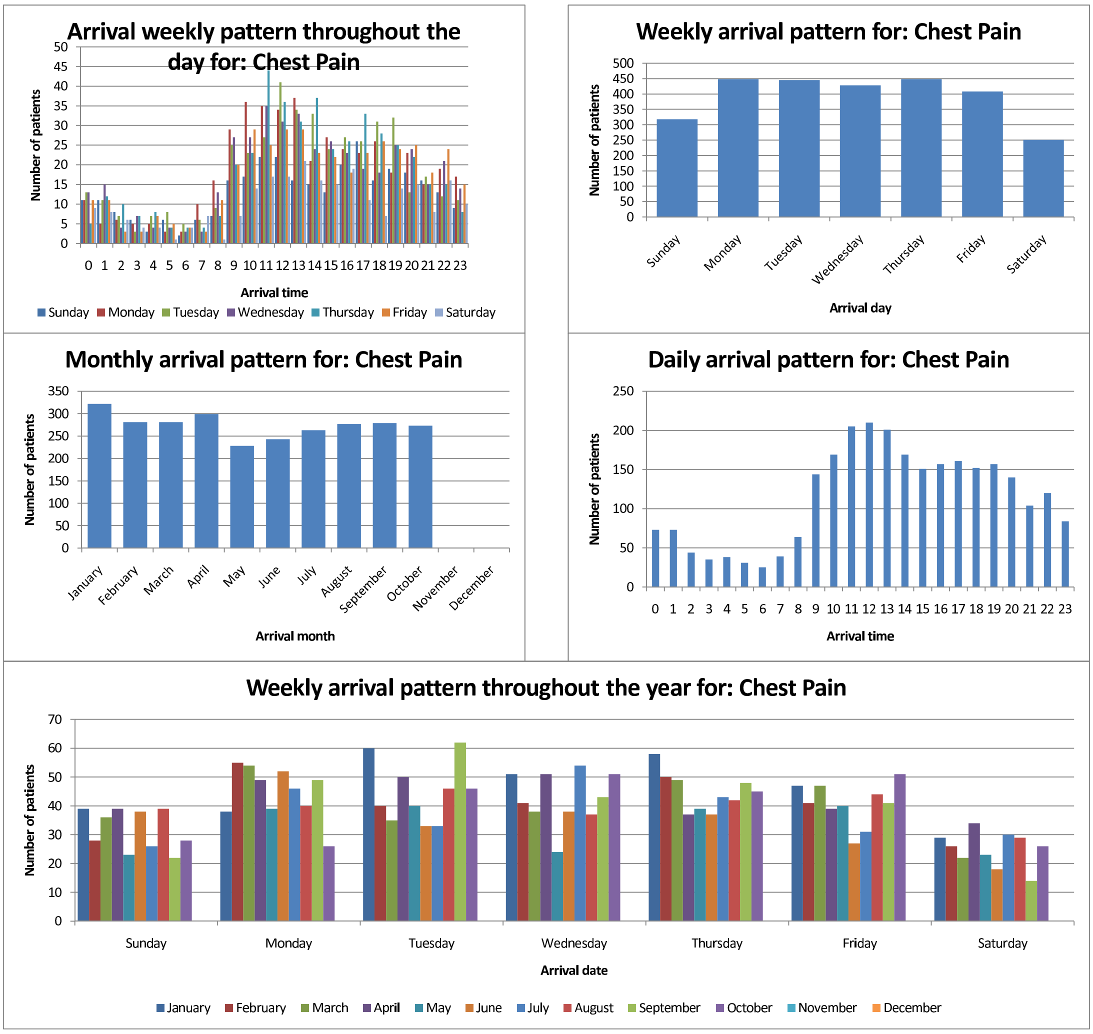


Figure 5.3: Histograms displaying the arrival distribution for Chest Pain patients

pattern (a), as for the above example this sheet is indexed as **CG(b)8_Chest Pain**.

Having prepared the necessary frequency tables the according histograms are displayed in the subsequent sheet addressed as **CG(c)8_Chest Pain** (to follow the previous examples).

The final sheet for each group displays pie charts for the remaining two categories, the referrals and the specialty where the investigated group belongs to a complaint group. The ratio of the sex and the triage class ration of each complaint group is also illustrated as a pie chart. Below the pie chart an age distribution for the certain group under investigation is plotted as a histogram. This final sheet is labelled as **CG(d)8_Chest Pain**, following the subsequent examples.

These steps above are repeated until all groups are analysed and processed. In the example for the patient data of the last ten months, the above procedure is repeated 94 times resulting in 470 sheets plus one index sheet, which allows for comfortable navigation through the sheets.

5.4 ED Simulation Modelling

The approach, 'how to conduct simulation research' is discussed in the third chapter, where the simulation methodology is outlined as a valid supplement to the existing quantitative and qualitative research methodology. The theory of this approach is straight forward and displays a sensible layout that is reasonable to follow in practice. However, as Law & Kelton (2000) stated, it is important to consider that the certain subsequent step might overlap whenever necessary (Chu et al. 2003, Gutjahr & Rauner 2007, Utley et al. 2003, Vissers et al. 2007). Banks et al. (2005) therefore proposed to consider data mining as a parallel task to conceptual modelling. This overlap of the different procedures is in practice inevitable, as it could be observed due to practical reasons, that not all quantitative data was available before the conceptual modelling phase. In this case for example, the qualitative interviews and flow charts were evaluated and used for conceptual modelling. As the quantitative data contribution only partially to the conceptual modelling this decision was a practical move in order to keep up the work flow.

This section lays out how the application of the FRA methodology could be included in the field work. It is therefore illustrated, how the field work is conducted by regarding the research methodology for simulation modelling. To highlight the construction of the model, the following procedures are displayed:

- Data mining – the essential steps on how the data is processed;
- Conceptual modelling – here the basis for the later translated simulation model;
- Transformation of the conceptual model – results in the executable model which stems from the FRA principle;
- Execution runs – explains the behaviour of the model and highlights special features;
- Verification and validation – proves that the model is a valid representation within the certain limitations;
- Optimisation – discusses how simulation techniques can be applied and delivers an example;
- Animation – used for presenting purposes but also applicable as a V&V technique.

Within this section the reader will see that the simulation research methodology is a valid approach and that the FRA combined with MPPM method is another very useful extension, which can be applied with considerable ease. This approach also increases the complexity of the model, but does not place a burden on the administration and maintenance of the model to the designer.

5.4.1 Complexity Considerations

Modelling DES contains an important aspect, which is the decision to consider which detail level is necessary to build a representative model, without considering all irrelevant details. In case all available groups are considered, 97 different groups would be displayed, of which each holds 6 different process times plus the total time and the arrival process data. If all should be considered separately in a model, it is understandable that the model would increase in size and would therefore be hardly manageable. In this case there would be 776 different processes as well as different routings for consideration. In order to reduce the complexity, two measures are taken: one is placed within the grouping data step of the DMM and the other is applied at the end of the DMM, where the retrieval of the statistical data is complete.

Patient Group Complexity

The first complexity reduction consideration investigates how the number of groups can best be reduced whilst still representing the actual ED under investigation. For that reason the complaint group is chosen and it is investigated whether there exists a threshold, where minor groups can be grouped in one larger general group, but still maintain the arrival pattern. The categories specialty and referrals are not considered, as they are later limited by the obtained qualitative data in case it is still required. In order to obtain a certain threshold, the distribution of the total time is investigated because this process includes all patient movements within the ED. To show at which point it is applicable and sensible to group minor groups in one large group, minority groups are withdrawn from the data set. The remaining data set is hence compared with the total time distribution of the complete data set. This comparison is done by calculating the correlation coefficient according to Pearson (Bronstein et al. 2008) between the two distributions, which is calculated as:

$$\varrho(X,Y) = \frac{Cov(X,Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}} = \frac{E((X-EX)(Y-EY))}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}} \tag{5.1}$$

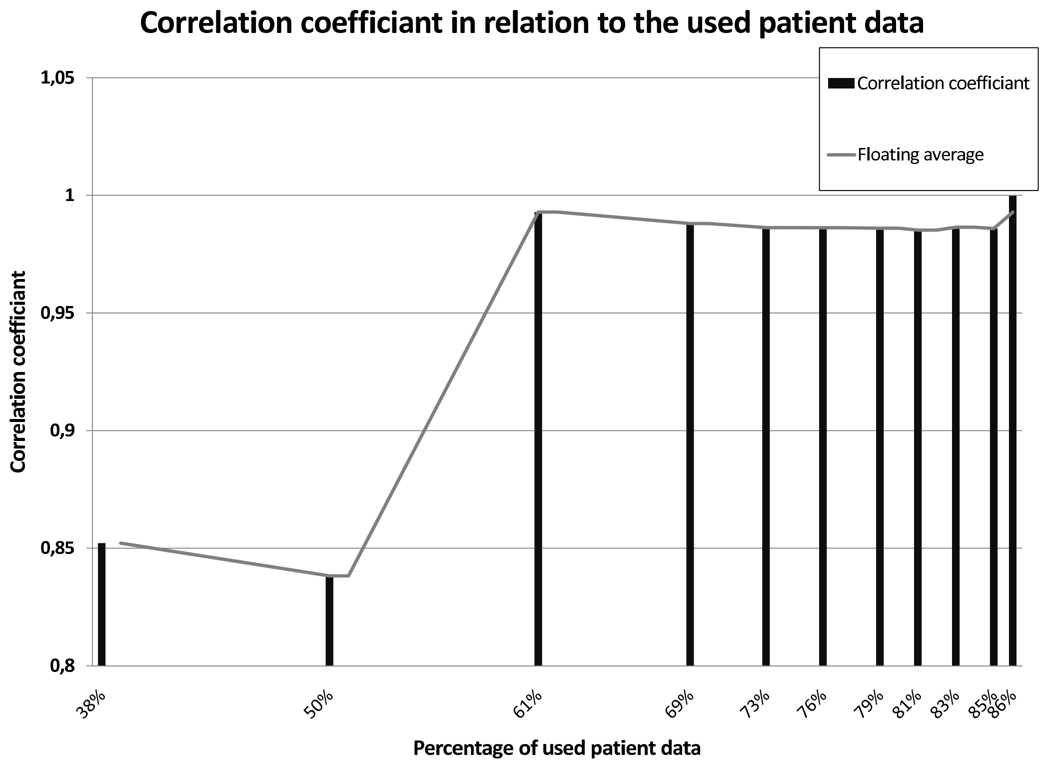


Figure 5.4: Correlation between the patient group size and the total number of patients in percentage

Graph 5.4 shows the correlation coefficient on the ordinate as calculated in (5.1) and the group size in relation to the total size as a percentage on the abscissa. When group size reads 62% this means that 62% of the data is left out and only the three largest groups remain in the data set. Table 5.1 shows the summed percentage according to the size of the groups.

Table 5.1: Ranked patient groups according to their appearance (Full Table see Appendix).

Rank	**Complaint-Group**	**Number of Patients**	**Accumulated Percentage**
1	Unwell Adult	3134	100%
2	Abdominal Pain in Adults	2499	79%
3	Shortness of breath in adults	1656	62%
4	Limb Problems	1639	51%
5	Chest Pain	1221	39%
6	Collapsed Adult	624	31%
7	Urinary Problems	445	27%
8	Falls	424	24%
9	Diarrhoea and vomiting	317	21%
10	Abscesses and local infections	301	19%
11	GI Bleeding	274	17%
12	Back Pain	271	15%
13	Headache	224	13%
14	Sore Throat	223	12%
15	Wounds	221	10%
16	Fits	137	9%
17	Major Trauma	115	8%
18	Mental Illness	105	7%
19	Head Injury	100	6%
20	Overdose and Poisoning	95	6%
21	Facial problems	90	5%
:	:	:	:
45	Haematological Disease	1	0%

Following the plot in graph 5.4, a trend can be observed, by which the higher the number of groups considered the higher the correlation coefficient. The trend is separated into three sections. The first sections below 50% show a base at a correlation coefficient of around 0.8 correlation. A steep incline is illustrated between 50% and 61% of data used, whereas after 61% of used data the correlation coefficient converges to 0.99. Assuming that a general error of 5% could be tolerated, then 50% to 61% of the original data would be needed, and the number of groups would be reduced by 45 to 4. A reduction of that degree arouses two major concerns: first statistical concerns; as the data is used for simulating an ED, it might not be the best choice to start with a large error potential. The second concern is that the model would only consider 4 patient groups (limb problems, shortness of breath in adults, abdominal pain in adults, and unwell adults); relevant groups for certain zones within the ED such as chest pain for Zone 1 where the majority of cases are to do with chest pain, would be left out or summarised in the remaining group. Therefore considering just 4 would potentially question the representativeness.

In order to maintain as much precision as possible, a trade off must be found where the administration of the model is in a fair relation to the detail level. It appears, that correlation coefficient converging to 0.99 is a reasonable value as in that case 9 special complaints groups would have to be considered within the model and one additional group which represents the remaining groups. With that measure, a fair amount of precision can be maintained, by reducing the amount of administrational work for the modeller. This observation is similar to the Pareto's Principle that is also recognised in de Bruin et al. (2007) and also in many other quantitative studies. In this case, adding another group, would not result in a significantly higher accuracy of the model, but would include a higher workload for the administration of the model.

Patient Routing and Exits

Another measure to reduce complexity is applied at a later stage, where the exits of the patients are grouped according to the qualitative interviews. The interviewees all specified 6 exits types as the most common types: patients are sent home, referred to another GP, admitted to inhouse hospital ward, referred to another hospital or specialty, or patients die. Based on expert opinion, the following 26 occurring exit types are grouped as listed in Table 5.2.

The exit routing is relevant to the system under investigation as the LoS of the patient within the ED depends on the exit route they take. As for example the DNW-group (DNW did not wait) show a shorter LOS than those who are waiting for admittance. Within this model, the wait for the admittance is considered as a part of the treatment process within the ED. It could be argued that this wait is a part of the hospitals' system, but as the waiting patients are using ED resources the wait is accounted to the ED.

Validate Routing

The patients routing within the model is validated once the first draft of the executable model is built. In fact, the validation of the routing accompanies the modelling design, because it ensures that the patients are routed correctly through the model. The use of animation helped to trace in cases where diversions were not taken correctly. To validate the patients routing, the original patient data is fed into the model and the distribution of the patients at the exits is compared with the patient data. In the final stage of the model design, the distribution of the patients exits at the simulation model correlate by 0.985, which indicates that there is a strong positive relation between the simulation outcome and the hospital data.

Table 5.2: Patient referral groups routed in simulation model.

Routing in Simulation Model	**Hospital Data**
Died	Mortuary
Different Hospital	Dressing Clinic ED Review Clinic Fracture Clinic Other Physiotherapy Transferred
Drop out	DNW Against medical advice Left before seen by doc
Home	Home - No Follow-up
Refer to GP	Private Follow-up Refer to G.P. Refer to Public Health Nurse
Ward	Admissions ADCC ADCC - Care of the Elderly ADCC - Dermatology ADCC - Endocrinology ADCC - ENT Clinic ADCC - GU ADCC - Hand Clinic ADCC - Liver ADCC - Ortho ADCC - Rheumatology ADCC - Vascular

5.4.2 Conceptual Model

To represent the mechanisms of the ED under investigation and also to consider the hierarchical structure and possibilities that come along with the simulation modelling environment, two conceptual models are chosen. The first model is a modified IDEF0 graph, which considers hierarchies and 'virtual' resources, that are used as mechanisms in order to contribute to the flexible resource allocation. The second conceptual model is based on a flow graph which merges all matching provided flow graph information. The flow graph illustrates the journey of the patient through the various stages in the ED, while the IDEF0 focuses on the hierarchical structure of the processes and the resource distribution for its processes. Both conceptual models are kept abstract, although they already provide a lot of details. Many processes and tasks are repetitive which are hence considered and summarised within the later executable structural model. The conceptual models are here considered as a modelling guide and a frame, to which the relevant information is later added.

Flow Chart Model

The flow chart is obtained from doctors and nurses who drew a flow chart of the patients of the most common complaint groups. As a result 14 different complaint groups were identified, which were all routed differently through the ED under investigation (Figure 5.5, see Appendix 7.5 for all 14 which are included in the IDEF0 booklet).

Figure 5.5 shows a flow chart of patients with urogynaecology complaints; one of the major 14 complaint groups. Merging all 14 complaint groups in one flow chart delivers a complex network with a sophisticated routing (see Figure 5.2 on Page 211).

The blue boxes indicate the typical stages of a patients' journey and the arrows with yellow labels attached, indicate the routing information of the relevant patient groups attached to the arrow. The patients' complaint is also equipped with a

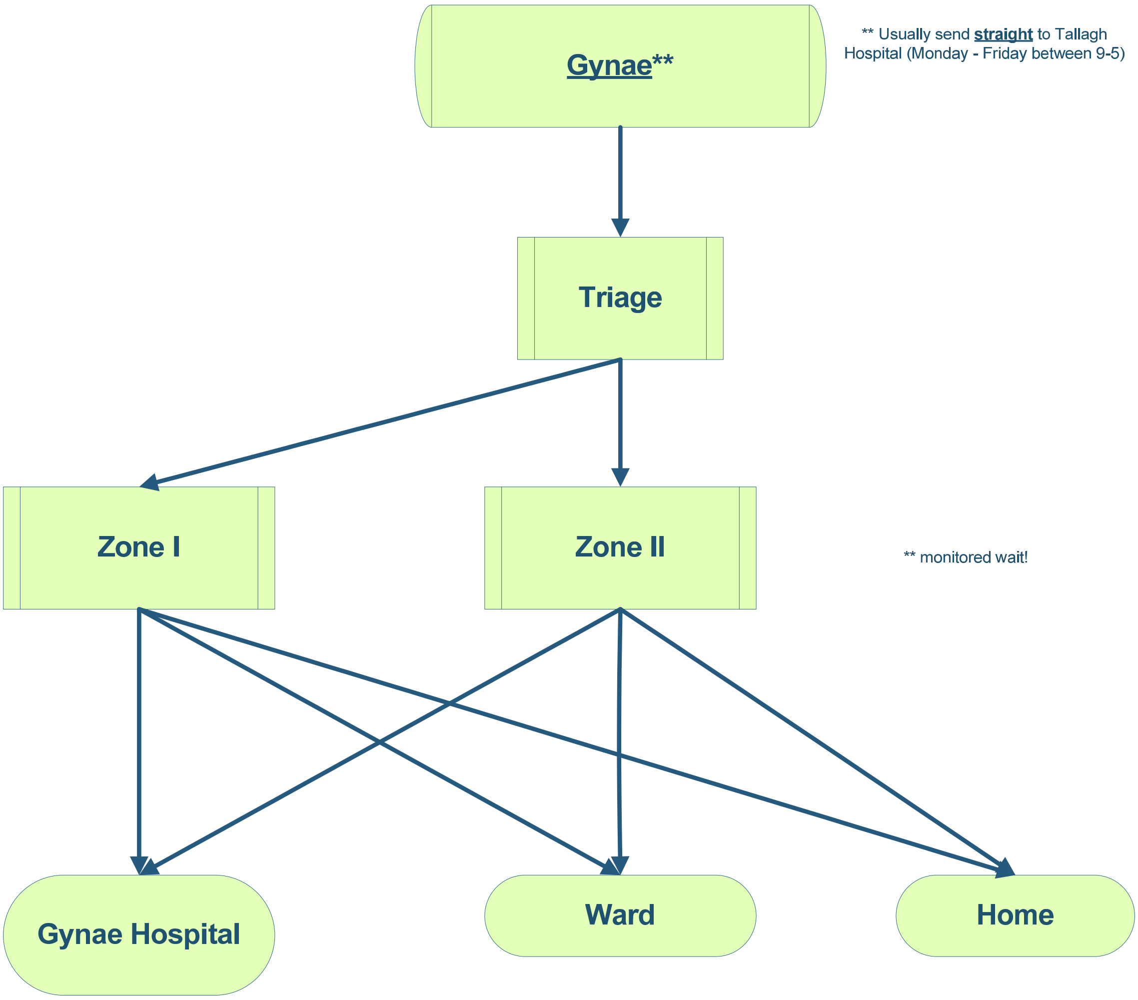


Figure 5.5: Flow Graph illustrating Gynae Patients moving through ED including all possible alternations.

severity level ranging from 1 to 7 where 1 is the highest. The severity level complies with recommendations of the triage level of the Manchester Triage Method (2005) – however, one adjustment was necessary in order to allow double routing of one severity level: medical staff stated in two cases of the triage level that the second and the third triage level may either take this route or the other route; therefore additional classes have been inserted in order to allow the mapping of the ”in between” levels. The first and the second levels match identically with the first and the second of the Manchester Triage method. The third Triage level is split up into third and fourth severity level with equal priority. The fourth triage level is also split up to create the 5th and 6th severity level, while the 5th triage level is referred to the 7th severity level. The indicators and the decision basis, where and when the original triage level is split up and why, could not be retrieved from the hospital data records. This phenomena is discussed with the medical staff and consultant and therefore the split groups are a necessity but as yet, unexplained.

To trace the patients' journey in the merged flow chart, the arrows contain tagged information fields in which it is shown how the patients are routed through the ED. The first letter indicates the origin of the patient, the first number in the brackets identifies the patient complaint (1 of the 14 most common listed in the Appendix 7.5 on page 321) and the second number indicates the severity level. The arrow points to the destination of the patients' journey. With this tagging system many arrows can be summarised, making the already complex graph readable for the modeller.

Final Conceptual Modelling

At this stage, a major modelling task is now completed: the conceptual modelling. In this field work, two different conceptual models have been built, which each deliver a different perspective on the ED under investigation: the process flow chart focuses onto the process flow and the stages of the journey of the patient, whereas the IDEF0 model provides a procedural insight and indicates when and where certain resources are used and at which stage. The combination of both modelling concepts provides a strong insight into the ED.

Having these two conceptual models at hand, which deliver two different perspectives on the ED, medical staff should be consulted and get an approval for the validity of the mapped processes. The IDEF0 booklet and the process flow model were completed within three months of having finished the observation of the ED. At this stage, both conceptual models were handed over to the chief consultant and discussed in detail. While the consultant checked the validity of the process mapping, the quantitative data was analysed according to the above described procedure. After having received the approval of the consultant, which triggers the start for the building of the actual simulation model, now four essential elements are at hand: two conceptual models, which deliver a different perspective on the simulation model. Quantitative data analysis, which provides the required statistical process data, and the data from the observations, should be used with care, as the required sample size could not be guaranteed. With these four components, a representative simulation model of the ED under investigation is feasable.

5.4.3 Modelling with model adjustments

Having completed the conceptual modelling, the data analysis, and having retrieved the first validation for the conceptual model, everything is prepared to start to build the simulation model. This step is named the transcription of the model (see chapter 3.3.2), where the conceptual model and all of the underlying data is transformed in an executable simulation model. The final model representing the ED is built within a simulation package as these allow a faster development of the model than development within a programming language. The major reason for a faster development is that within simulation packages the required functions are prebuilt and ready for its use, in comparison to a development in the programming language, where those functions need to be programmed, or defined.

Modelling Environment

Applying the FRA framework requires certain properties of the simulation environment, which should support the following core features:

- Hierarchical modelling;
- Local variables;
- Pooled resources;
- Random variate generator;
- Customizable performance measures.

Within this field work, a simulation software package has been chosen where all of the above features were supported. Additional reasons for its are its usability, the possibility to modify and enhance predefined modules, and the flexibility of the data handling.

The usability is one important aspect, which is achieved by allowing the modeller to arrange modules in predefined blocks that can be connected as in flow charts. Therefore the connected block arrangement appears similar to the conceptual flow chart, which eases the modelling and also reduces the error-proneness.

Another argument for the simulation software package has been that the source code of the blocks can be easily modified and if necessary even be reprogrammed for special use. The compiler of these modules is very fast and allows an instant and quick manipulation even within the existing model, without the need to recompile external libraries.

A further important aspect is the flexibility provided for the data handling. Data can be easily imported and exported by various numbers of interfaces. Import and export filters allow exchanging data via text editors (ascii), general spreadsheet calculation programmes and database orientated files (for further details please refer to the manual (Mackway-Jones et al. 2006)).

Using a simulation software package shall not limit the use of the FRA to these certain simulation packages, and should instead be considered as a proof of concept, which is applicable in other simulation packages which provide similar features.

Translate the conceptual to simulation model

The two conceptual models deliver different perspectives on the model under investigation, therefore their translations into an executable simulation model differ in detail. The simulation model is structured with five main sections: the first section represents the entrance and the configuration of the patients. Here the patient arrives according to the time table, which is taken from the hospital records. The properties of the patients such as complaint group and triage class are assigned randomly according to the distribution retrieved from the hospital records. With that measure, the arriving of the patient is fixed but the variation of the routing is given due to the random allocation. According to the complexity reduction measures only 13 complaint groups needed to be considered, which are here reserved for each special treatment unit (zone 1 to 3). The 14th group, arranges the remaining minor complaints into one large general complaint group which is randomly allocated under the consideration of the general routing distribution for all remaining patient groups. This general routing information also applies to the treatment units according to their assigned complaint. In general, the routing of the patients is established by their complaint and triage class. In addition to this it is stated whether the patient arrived on their own or was delivered by ambulance. In cases of arrival via ambulance a different routing applies. Different routing applies also for emergency cases which may apply to the highest two triage classes. Ambulance arrival and emergency cases skip the registration and the triage. Detailed information on the routing of the patient and configuration can be retrieved from the calculation spreadsheet which can be found on the DVD in the Appendix – a brief summary is included within the hierarchical block *"patient properties"* of the simulation model, which allows a quick verification of the applied data.

The patients' flow mapping refers to the second section and contributes to the whole of the model. The routing of the patient and resources are obtained from the process flow chart in order to map the journey of the patients. Here the main stations like registration, waiting room, triage, zone 1 to 3, diagnostic imaging, clinical decision unit, and cardiac care units are laid out. The connections are drawn according to the process flow chart. The routing of the patients, such as the ratio at diversion points is obtained from the analysis of the hospital records and confirms the routing established in the process flow model.

The third section refers to the process mapping and the actual application of the FRA framework. The FRA framework also includes the fourth section which is the resources' process flow and distribution, but first the translation of the IDEF0 models into the simulation model is laid out. Observing and studying the IDEF0 models shows that within the different treatment units (zones) processes, the integrated tasks share a high degree of similarity. The main difference among them is basically the time distribution for the processes, as chest pain treatment involves more care and attention as a displaced shoulder socket. In general the treatment chain of processes within the zones is described as follows:

- Prepare cubicle (arrange medical equipment, bed and chairs);
- Place patient in cubicle;
- In depth interview;
- Depending on previous interviews external medical imaging might be needed;
- Consultation (doctor, senior doctor and/or consultant);

- First treatment;
- Release;
- Cleaning of the cubicle.

Within those processes the activities differ significantly, but as this hierarchy level is regarded to be sufficient, details such as process times of taking blood samples or of measuring blood pressure are not considered. Adding this detail would create a high degree of workload for the analyst and would only add a little additional information to the context of the patients' journey. Therefore, determining the different process times for the above illustrated meta-process shall be sufficient.

The FRA framework can be located as a module if necessary, which can be embedded as a block within a simulation model. The "FRA-block" then requires certain information in order to automatically lay out the treatment chain and to connect the relevant resources. The required information is:

- Length of the treatment chain (here: treatment process chain within the zones);
- Number of treatment chains (here: zones);
- Total number of different resource types (here: 11).

The actual number of resources is defined later in an external spreadsheet which is used for the actual resource distribution. Having provided this information in a separate model sheet, the model must be executed. As described in section 4.1.3 on page 160, the simulation package executes the FRA-block in the pre-run execution phase and connects the processes automatically. According to the number of provided resource types, they are connected with the processes via address binding – in the simulation software package this technique of 'pathfree – connection' is referred as 'catch' and 'throw'. These blocks are therefore used to direct the resources to the appropriate process according to the resource allocation table (see Figure 4.8

on page 180). Once the FRA-block is finished the resulting deflated model must be inserted in the actual simulation model. At this stage, a few minor manual adjustments are required.

Manual changes are required in order to embed the output of the FRA-block in the actual simulation model and those adjustments involve the connection of the item paths to the several zones and the connection of value connections which indicate the actual zone number (those are used as an address) and those which indicate the capacity limits (cubicle capacity and additional corridor capacity). The next manual adjustment is to place the resource allocation spreadsheet table within the same folder as the simulation model, and to fill out the table according to data obtained from the qualitative interviews. The table is set up in two sections, the lower part (grey) displays the quantities needed, while the upper part (orange) displays the process times. The process times here use log normal distribution characteristics due to the fact that a general statistical distribution could not be retrieved and that lognormal distribution is a common distribution for healthcare processes according to McGuire (1998), (National Institute of Standards and Technology 2010). The final manual adjustment is to set the attributes of the patients, where the process times, the taken routes, and the patients' configuration is stored. This can be time consuming depending on the number of processes and the number of process times which are relevant for the later model analysis.

With the integration of the treatment units, resource pools are now available. These resources, such as medical staff, are routed to the processes of the treatment unit, so that they are available on request. As these resources have additional tasks, it is now possible to consider them within the active pathway. The passive pathway describes the journey of the patients and the active pathway considers the tasks and duties of the resources in order to accomplish the process which the passive pathway participant passes through. This *"interlinked pathway modelling of limited connected resources"* – also referred to as multiple participant pathway modelling (MPPM) –

is applied within this step of modelling, which is one of the final adjustments of the simulation model. The modelled tasks and duties of nurses and doctors are summarised as documenting processes which are completed after the medical staff have visited the patient. In reality the documentation task is more complicated, as the nurse must acquire the paper based patient file and compare the data with the data on the electronic record if available. If there is doubt, a new electronic record for the patient must be created. Following the interview with the patient, the new found data and treatment must be documented on the electronic patient record. Within this simulation model, the process duration documentation is initially left blank. This is used in the later phase of the scenario testing, where the aim is to ascertain the impact of the documentation on the remaining process times dedicated to the patients. This is presented in the later scenario testing (section 5.7 on page 248).

The fifth and the last section of the simulation model is describing the referral of the patients. Here the patients are routed to the several exits and all relevant logged data can be obtained from the attributes of the patients. This data can either be stored in a database or directly written onto a spreadsheet. In this case, the simulated patients' data is written onto a calculation spreadsheet which allows the application of the data analysis sub routine, which in turn eases the verification of the simulation model.

To finalise the model construction, the process times, retrieved during the data analysis, must be inserted. The following stages are documented with the process times from the patient record:

- Wait for Triage;
- Wait for Treatment;
- Time in Waiting Room;
- Treatment Time 1 (excluding Clinical Decision Unit (CDU));

- Treatment Time 2 (including CDU);
- Wait for Admittance;
- Total Time.

Unfortunately, the resolution of the processes is not very high, which means that, for example, how long a patient has stayed within a certain treatment unit is retrievable (Treatment Time 1), but the time of every process step is not retrievable. In order to solve this issue, process time data is obtained from first simulation runs and compared with the process times from the patient records. In cases where the process times are different, the process times of the treatment unit of the simulation must be altered by applying the bisection method. To find the initial process times, the data from the observations was used as a first orientation value. The data obtained from the observations was very general and not representative as it is impossible to trace all variations of the patients' journey through the ED. Therefore the data obtained from the observations can only be used for orientation and as a starting point for the bisection method: to retrieve the most accurate process times, the average total process time from the simulation model R are used and compared with the averaged hospital records H, which are obtained for the specialties which are located within that certain unit (Table 5.3 illustrates the alteration for the chest pain unit (zone 1)). The next set of s_{n+1} is adjusted according to the difference D_1 with the consideration of the variations of the results. D_2 is related to the ratio between the setting of the processes s_n and to the subsequent setting s_{n+1}. The bisection method is usually applied to continuous functions; therefore, here the method is slightly adjusted to the occurring variance of the simulation model. In general, the bisection method is applied to a continuous function F which has an interval $[l, r]$ at exactly that zero point, where $f(l) < 0$ and $f(l) > 0$, which results in the following algorithm:

1. Set $l = a$ and $r = b$;
2. Test whether $[l, r]$ contains a zero point, if not: stop;

3. Test if $r - l < \epsilon$, if so than the final interval which contains the solutions is found;

4. Else divide the interval $[l, r]$ and continue the algorithm with the two new intervals recursively at point 2.

This bisection method requires modification due to the fact that the test is not done towards a zero point, but to the average of the hospital record H. Another consideration must be taken into account, namely, that the simulation model does not deliver a continuous function, therefore the interval which is usually halved, is here estimated on behalf of the difference D_1 (see Table 5.3). The stopping criteria for the algorithm here is chosen as 5% maximum difference to H. Difficulties arise as the algorithm is not working when isolated to one treatment unit. As all three are connected within the same model: queues on one unit have an impact on the remaining two; therefore the algorithm must be monitored and adjusted manually. That is the reason why $D_1 \neq D_2$.

In order to minimise the variance of the simulation results, the simulation model calculated the patient arrival and processing for the time span of three months with the arrival data from the hospital records. The runs were repeated 10 times which hence was used for the averaging. A warm up period of 250h was granted, which is the equilibrium of 500 patients; more than necessary, as calculated in section 5.3. This guarantees however, that the model is in a steady state.

Calculating the estimations for the process times is a pre-emption of methods used in the later verification and validation phase. Due to the provided data and the observations, it is possible with the use of the modified bisection method, to find estimations that would fit with the hospital records. However, after having found the set of the process distribution, an approval from the medical staff is required at this stage. This involves confirmation of the timings found here.

Table 5.3: Bisection method to identify treatment process times.

Run number	Simulation setting - Total time of treatment unit	Simulation results of treatment unit	Hospital records of treatment unit	Differenz between hospital results and simulation output [%]	Change of simulation setting to the subsequent [%]
n	s_i	*R*	*H*	D_1	D_2
1	35	180.42	222.42	-19%	15%
2	41	340.34	222.42	53%	-8%
3	38	289.17	222.42	30%	-15%
4	33	258.1	222.42	16%	-18%
5	28	209.36	222.42	-6%	3%
5	29	210.28	222.42	-5%	

5.5 Verification and Validation

Balci (2003) gives a brief differentiation between verification and validation by stating that "verification deals with the assessment of transformation accuracy" and "validation deals with the assessment of behavioural or representational accuracy" (Balci 2003, p. 150). The assessment of the model with verification and validation guarantees the modeller and the stakeholders the correctness of the model in order to gain confidence which is necessary for acceptance of user to-be. Verification and validation is therefore an essential part of the modelling procedure.

The verification ensures that the conceptional model is correctly transformed into the computerised model and still resembles the actual system. Balci (2003) proposes that the verification should accompany the whole modelling and simulation process. This is because methodologies taken from Software Engineering can be applied, for example development and design techniques like exploratory or incremental development or prototyping design, reused-based design, or concepts like spiral, top-down, bottom-up or waterfall. These techniques mean that the process quality is ensured on a large scale throughout modelling, while programming techniques assure process quality within the model.

According to Balci et al. (2001), the verification and validation has accompanied the construction of the simulation model throughout the whole transformation process: the first verification and validation technique applied has been to trace the item through the model with the use of animation (Balci et al. 2001). To confirm the correct routing, the correlation coefficients of the outputs and of the routing within the model were retrieved and analysed (see section 5.4.1). The patient arrival times were used from the hospital records and used as the input for the simulation items. This measure provides the advantage that the error of having chosen the wrong patient arrival time distribution can be excluded. The routing however was generated randomly according to the routing distributions found in the hospital data where the patient complaint groups were treated by different specialties. These specialties were allocated in different treatment areas, and therefore the routing distribution could be established from that source. The high correlation coefficient confirms that the routing of the patient is within acceptable parameter range.

For the verification of the simulation results, it is helpful to retrieve data at the same points where they are retrieved in the real system. This measure allows the application of the same tools and techniques which were used for data analysis. Having the same analysis methods at hand, a comparison of data is hence more valuable, as methodical error can be reduced to a minimum – or at least it was compared with the same error.

In order to verify the model correctness, data is obtained from the model which reflects the equal process steps as they are documented in the hospital records. The advantage of having chosen this data, is that a comparison is made with the same tools as are used for the data analysis. For that reason modules of the DMM are used to calculate the averages, standard deviations, and the quartiles from the durations of each relevant process step. Additional modules are created in order to take repetitions of the simulations runs into account. These repetitions firstly reduce the variance of the averages, and secondly, allow the calculation of confidence intervals for the results of the simulation run.

The simulation runs were scheduled for the same time frame as the hospital

Table 5.4: Comparison between input process parameters and output simulation results.

Input - Output comparison	Process Stage / Statistical characteristics	Treatment Unit 3	Treatment Unit 2	Treatment Unit 1
Simulation results (for 2008)	**Total Average**	**146.72**	**163.81**	**216.48**
	Standard Deviation	2.95	2.61	8.25
Input parameter in total (log-normal distributed)	**Total Average**	**98.00**	**89.00**	**29.00**
	Standard Deviation	126.12	98.47	39.16
	Location	26.91	39.04	7.30
Additional process time (Percentage)	**Difference**	**48.72**	**74.81**	**187.48**
		50%	**84%**	**646%**

records, which involved approximately 35,000 processed patients. An equal warm up period of 250 hours was granted. The model timings themselves were set in minutes, therefore the process times and LoS are of the same time unit. The total LoS of the treatment units differ significantly from the sum of the process input parameter R which is the sum of the sub-processes s_n:

$$R = \sum_{i=1}^{n} s_n \tag{5.2}$$

The resulting differences can be obtained from Table 5.4 which illustrates the simulation output averages and the input parameters for the process times. The input parameters are identified by applying the bisection method recursively until the simulation output averages match the averaged hospital records by a deviation smaller than 5%. The difference between the sum of input parameters and the simulation output can be explained by the fact that the items (patients) must wait in between the processes until either a resource (nurse, doctor, etc.) is available or until the process itself is available. The process time indicates how much time the resource has spent with the patient. The patient journey through the specific treatment units also includes the wait for the results and the availability of the resources.

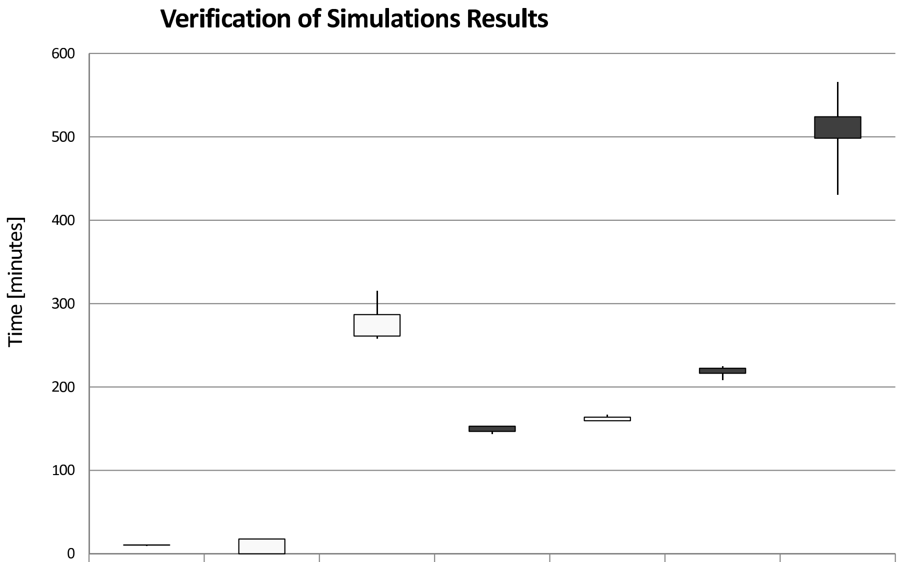
Table 5.5 shows the comparison of the summary of the hospital process times

Table 5.5: Verification of the simulation data with the hospital data

Data origin	Process Stage / Statistical characteristics	Waiting Room (first wait)	Waiting Room (second wait)	Treatment Unit 3	Treatment Unit 2	Treatment Unit 1	Length of stay
Hospital records (whole year 2008)	**Target Value for 2008**	**10.61**	**261.05**	**152.94**	**159.57**	**222.42**	**524.03**
	STDev: Target Value for 2008	10.46	246.95	196.83	176.55	300.38	745.53
	Location: Target Value for 2008	4	90	42	70	56	56
Simulation results (for 2008)	**Total Average**	**10.43**	**286.77**	**146.72**	**163.81**	**216.48**	**498.32**
	Standard Deviation	0.63	28.59	2.95	2.61	8.25	67.36
	Confidence Area 95%	0.44	20.14	2.08	1.84	5.81	47.46
	Confidence Area 99%	0.63	28.65	2.96	2.62	8.27	67.50
	Confidence Interval 95% [Lower bound]	9.98	266.63	144.64	161.97	210.66	450.86
	Confidence Interval 95% [Upper bound]	10.87	306.92	148.80	165.65	222.29	545.78
	Confidence Interval 99% [Lower bound]	9.80	258.12	143.76	161.19	208.21	430.81
	Confidence Interval 99% [Upper bound]	11.05	315.43	149.68	166.43	224.75	565.82
Comparison of results	**Difference to Target Value**	**1.7%**	**9.9%**	**4.1%**	**2.7%**	**2.7%**	**4.9%**
	Error Rate based on 95% Confidence Interval	4.2%	7.0%	1.4%	1.1%	2.7%	9.5%
	Error Rate based on 99% Confidence Interval	6.0%	10.0%	2.0%	1.6%	3.8%	13.5%

– LoS – with simulation results by taking the confidence intervals into account. In Table 5.5 it is illustrated, that the averages of the process steps differ within 5% range (best 1.7%, worst 9.9%), with the exception of one outlier which is 9.9% wait in the second wait. Even though here there is a relatively high difference, the difference is still within the 99% confidence interval which is 10% for the second wait in the waiting room. An additional important consideration for the interpretation and verification of results, is that the averages of the hospital process times of four of the six main processes are within the 99% confidence interval. It can therefore be said that the probability that the simulation result is within that range is 0.99. These processes are the following LoS: first and second wait in the waiting room, treatment unit 1, and the total length of stay. The LoS of treatment units 3 and 2 are not within the 99% confidence intervals, but the averages do not differ more than 5% in the direct comparison of the averages (4.1% and 2.7% for treatment unit 3 and 2 respectively). The box plot 5.6 provides a visual impression of the verification results listed in Table 5.5.

Drawing from the experience of the applied field work, it can be said that the common verification and validation methods, as laid out in section 3.3.2 (page 121), are applicable in order to evaluate the models' accuracy. However, it could be seen that animation proved exceptionally useful with regards tracing the elements



	Waiting Room (first wait)	Triage	Waiting Room (second wait)	Treatment Unit 3	Treatment Unit 2	Treatment Unit 1	Length of stay
Target Value for 2008	10,61	0	261,05	152,94	159,57	222,42	524,03
Confidence Interval 99% [Upper bound]	11,05	17,75	315,43	149,68	166,43	224,75	565,82
Confidence Interval 99% [Lower bound]	9,80	17,58	258,12	143,76	161,19	208,21	430,81
Total Average	10,43	17,66	286,77	146,72	163,81	216,48	498,32

Figure 5.6: Box-Plot of the verification results for each section within the ED.

through the system especially when the active pathways described by the FRA should be debugged. In this case the limitation that the animation could only display sequential flows – even parallel executed events are displayed sequentially – turned out to be of value for debugging, because the conjunction of activities could be more easily pursued.

The comparison of results for the verification of the correct model translation, indicate that the overall process times and the initial identified process inputs s_n are within acceptable range. Thus the model can be considered as a representative reflection of the processes within the ED under investigation. This model is then used to test scenarios which investigate the impact of documentation on the processes and indicate how queuing time can be reduced by integrating measures which reduce the documentation time. An example of such a measure is the introduction of tablet PCs. Further, the model will be used to find an optimised distribution of the resources, here focusing on the medical staff distribution.

5.6 Animation

Animation has proven itself to be of great value for documenting the results of a simulation model as it provides a good guidance for the modeller and for the non-simulation modellers, to increase their understanding of the model (Balci 2003). Coherences and routing can be visualised and hence easily understood by the user and the stakeholders, due to reduced information in an animated 2D-plane. Creating a thorough understanding of the model via animation is therefore a good way to generate trust for the model among the stakeholders. Graphical user interfaces (GUI) hence allow interactions in order to test certain scenarios. Many simulation packages offer solutions for animation purposes which allow the tracing of items through complex routing. As mentioned above, animation is one useful tool among many verification and validation strategies, to prove that the model is behaving as intended (Gonzalez et al. 1997). However, as the complexity of models increases, the modeller is challenged to find appropriate illustrations to summarise the model in an appealing manner. Augmented reality or complex 3D-animation are both interesting and applicable tools for this situation.

Apart from the complexity of this model, the animation is chosen to be in a 2D- plane, because a third dimension, despite the fact that it is pleasing to the eye, would only confuse and distract the observer. The animation is applied with the animation tools provided by the simulation software package, which has certain limitations: number of animated items is limited (maximum 256 animated reserved fields for animation), co-occurring discrete events are animated sequentially even though they are processed at the same time index. The consequence of this is that co-occurring active pathways are not identified as such. The first limitation is considered in a way that the model displays only full queues with its full queues which are relevant, such as the queue to the registration and the waiting queue. All other queues are indexed with an icon for a group of people and a label which displays the length of the queue if the queue is longer than one item.

The second limitation is that parallel occurring active pathway loops, describing the input and output route between pools and activities, are not displayed. This is a major limitation to the understanding of the processes. Consecutive movement of the items parallel to occurring tasks is here misleading and delivers a false impression of the dynamics within the system under investigation. Therefore the animation of the active pathways is neglected as the animation still delivers an important contribution to the development of the queues within the model. The secondary pathways however could be applied with "Proof Animation" or either with the 3D-Animation library provided within the simulation software package. Applying and adapting either of these concepts would have expanded the scope of this dissertation and should be referred to as a matter for future potential research projects.

A screenshot of the animated model is displayed in Figure 5.7, where the layout is illustrated in a schematic, in which the patients are animated with moving icons which resemble five different types of people. Beds on the corridor resemble trolleys which are placed there and which indicate that the actual treatment unit has reached its capacity limit. The staffing level parameters can be changed directly during the simulation run on the same sheet of the animation allocated on the right side of the animation. In addition to the staffing level, the process timings and the resource requirements can easily be changed in the spreadsheet, which is also used for the configuration of the treatment units.

In a separate window, key performance indicators can be retrieved from the simulation during runtime (Figure 5.8). These indicators are the queue length, average waiting time, average treatment or process time, resource utilisation, average waiting and treatment time, and averaged accumulated time. These KPIs are retrieved from the following stages of the patients' journey: registration, triage, waiting room, treatment unit 1 to 3, radiology, CCU and CDU. A total is calculated on the average accumulated time of the patients' journeys. Figure 5.8 delivers an impression of the development of the activities within the process during runtime. Table 5.6 illustrates

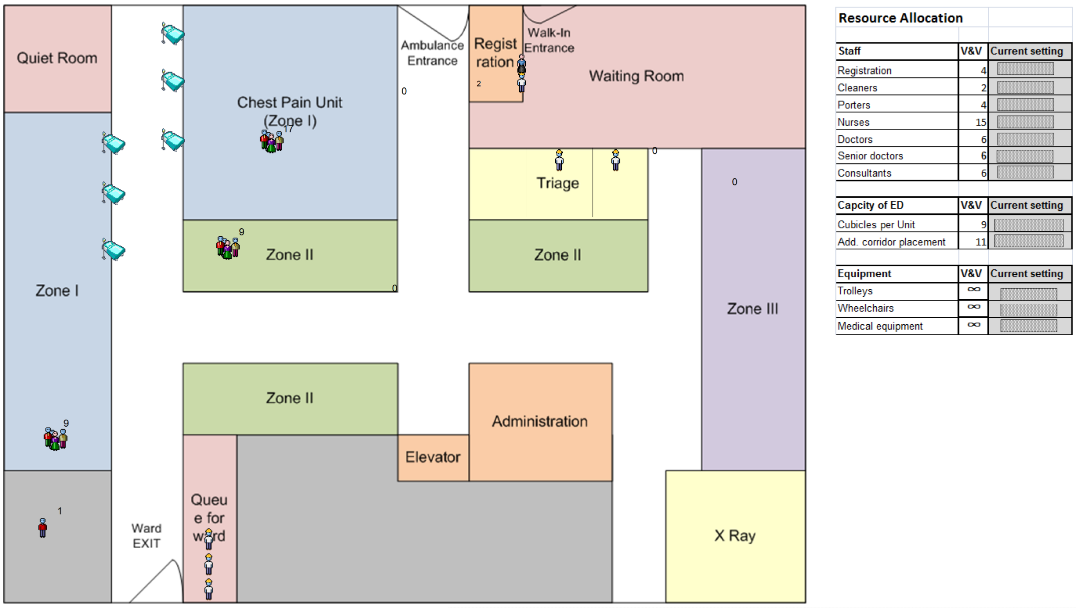


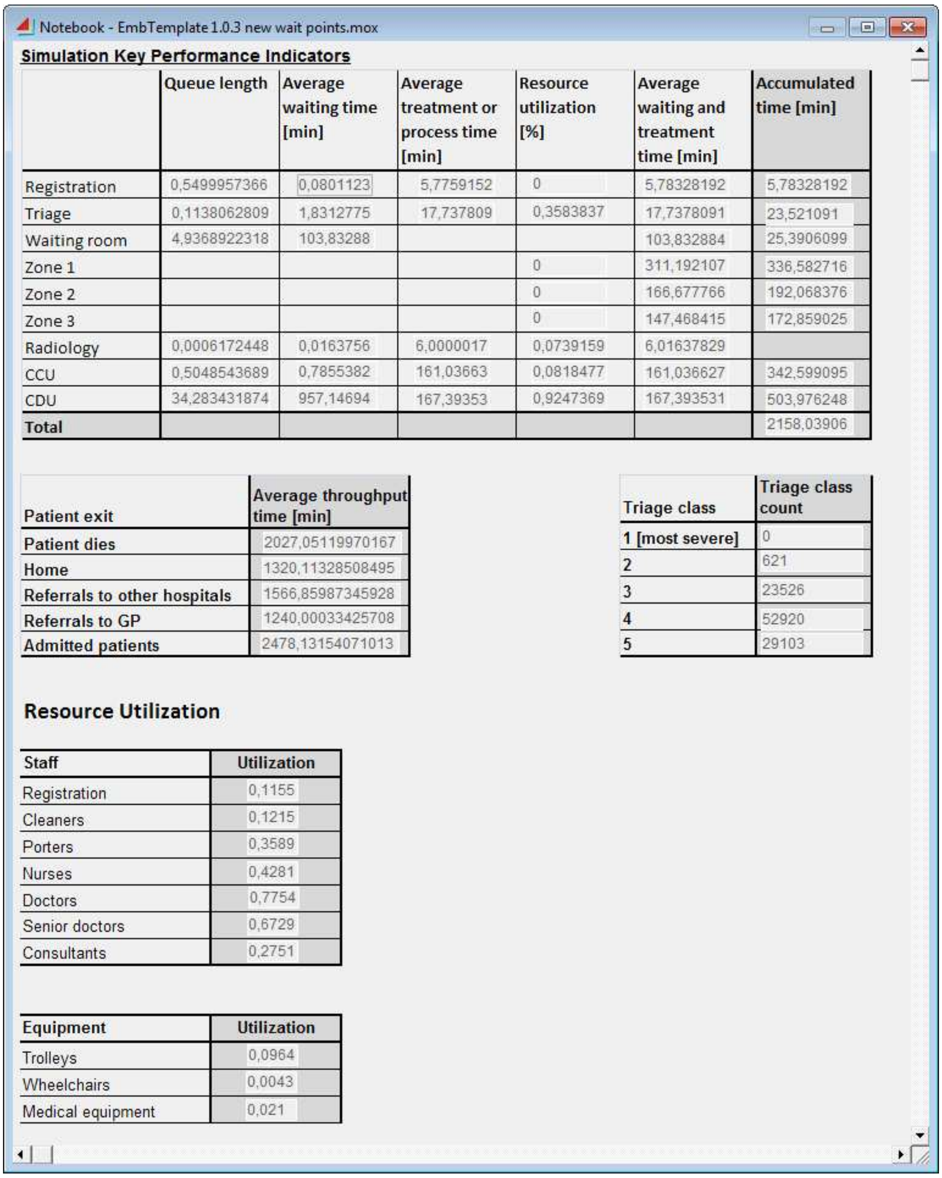
Figure 5.7: Screenshot of the animation of the Simulation-ED tool, which allows to trace the patients through the virtual ED.

the different Los (throughput time) for each of the five different exits. Last but not least, the user of this simulation model gets an overview of the distribution of the triage classes within the model.

By providing this particular GUI, the user of the model is in control of the parameter setting and can retrieve important KPIs at a glance. It therefore enables the user to retrieve relevant information with relatively little effort. In addition to the GUI, the user is also provided with spreadsheet, a calculation tool which calculates the relevant LoS. With these measures the user can also test in detail, scenarios for further decision making and planning.

5.7 Decision Analysis

The simulation model allows testing scenarios without interfering with the systems under investigation. The results can be used as additional information for the decision makers in order to reduce the risk of making a misjudgement or incorrect decision; errors which are difficult to correct. Avoiding such risks saves a lot of



Simulation Key Performance Indicators

	Queue length	Average waiting time [min]	Average treatment or process time [min]	Resource utilization [%]	Average waiting and treatment time [min]	Accumulated time [min]
Registration	0,5499957366	0,0801123	5,7759152	0	5,78328192	5,78328192
Triage	0,1138062809	1,8312775	17,737809	0,3583837	17,7378091	23,521091
Waiting room	4,9368922318	103,83288			103,832884	25,3906099
Zone 1				0	311,192107	336,582716
Zone 2				0	166,677766	192,068376
Zone 3				0	147,468415	172,859025
Radiology	0,0006172448	0,0163756	6,0000017	0,0739159	6,01637829	
CCU	0,5048543689	0,7855382	161,03663	0,0818477	161,036627	342,599095
CDU	34,283431874	957,14694	167,39353	0,9247369	167,393531	503,976248
Total						2158,03906

Patient exit	Average throughput time [min]
Patient dies	2027,05119970167
Home	1320,11328508495
Referrals to other hospitals	1566,85987345928
Referrals to GP	1240,00033425708
Admitted patients	2478,13154071013

Triage class	Triage class count
1 [most severe]	0
2	621
3	23526
4	52920
5	29103

Resource Utilization

Staff	Utilization
Registration	0,1155
Cleaners	0,1215
Porters	0,3589
Nurses	0,4281
Doctors	0,7754
Senior doctors	0,6729
Consultants	0,2751

Equipment	Utilization
Trolleys	0,0964
Wheelchairs	0,0043
Medical equipment	0,021

Figure 5.8: KPI tables to document the development of KPIs during the simulation at runtime.

Table 5.6: Raw verification results directly retrieved after ten simulation runs.

	Zone3	Zone2	Zone1	Length of stay	Summed waiting time
Target Value for January	**152,94**	**159,57**	**222,42**	**524,03**	271,66
Run number: 0	145,668037	164,015233	213,28611	541,993631	365,766029
Run number: 1	153,046896	168,16984	232,704535	534,396261	350,979164
Run number: 2	147,076695	164,318951	233,919693	520,552693	332,010453
Run number: 3	148,794364	162,549535	217,044346	435,164099	253,404987
Run number: 4	144,400205	163,148599	213,223124	463,573801	285,270166
Run number: 5	141,528358	161,487204	201,905443	448,147835	275,458495
Run number: 6	153,033969	165,950358	230,811411	449,297285	262,034187
Run number: 7	142,892109	161,558094	206,599851	538,787601	367,904033
Run number: 8	145,382989	164,217953	211,265729	509,326307	332,553406
Run number: 9	152,178355	169,403314	246,069485	525,285183	331,973633
Total Average	**147,400198**	**164,481908**	**220,682973**	**496,65247**	**315,735455**
Standard Deviation	*4,2081212*	*2,65246532*	*14,2595229*	*42,5280226*	*42,9436531*
Confidence Area 95%	*2,96485478*	*1,86880893*	*10,0466247*	*29,9633506*	*30,2561854*
Confidence Area 99%	*4,21706678*	*2,6581039*	*14,2898356*	*42,6184283*	*43,0349423*
Confidence Interval 95% [Lower bound]	144,435343	162,613099	210,636348	466,689119	285,47927
Confidence Interval 95% [Upper bound]	150,365053	166,350717	230,729597	526,61582	345,991641
Confidence Interval 99% [Lower bound]	143,183131	161,823804	206,393137	454,034041	272,700513
Confidence Interval 99% [Upper bound]	151,617265	167,140012	234,972808	539,270898	358,770398
Difference to Target Value	**96%**	**103%**	**99%**	**95%**	**116%**
Error Rate based on 95% confidence interval	*2%*	*1%*	*5%*	*6%*	*10%*
Error Rate based on 99% confidence interval	*3%*	*2%*	*6%*	*9%*	*14%*
Fluctuation	***-4%***	***3%***	***-1%***	***-5%***	***16%***

Table 5.7: Comparison of the LoS within the Zones.

Scenario I: Impact of documentation	Process Stage / Statistical characteristics	Treatment Unit 3	Treatment Unit 2	Treatment Unit 1
Process times without documentation	**Total Average**	**146,72**	**163,81**	**216,48**
	Standard Deviation	2,95	2,61	8,25
Scenario results: Added documentation	**Total Average**	**163,23**	**178,58**	**331,47**
	Standard Deviation	5,96	4,02	22,28
Additional process time	**Difference**	**16,51**	**14,77**	**114,99**

resources in the form of time and costs, especially considering the costs of erasing a false decision. In healthcare for example, the decision makers try to minimise as many risks as possible in order to keep the patient as safe as possible. The model constructed here is one tool which increases the transparency of the system under investigation and allows sound decision making. In order to demonstrate this procedure, the following two scenarios are tested: first, the impact of additional documentation and second, the potential benefits of employing an additional doctor.

The first scenario is motivated by complaints received from the medical staff who complained about the high level of documentation effort which they must accomplish during their duties. Therefore an investigation will look at the impact which could be achieved, if the documentation effort were reduced by one minute per patient per treatment step, with improved documentation aids such as Tablet-PCs and PACS.

This scenario is a very good application for the "interlinked pathway modelling of limited connected resources" as the documentation is not applied to the patient, but yet occupies the medical staff. In recent models, as shown in the literature review, this problem could not be answered, or was simulated insufficiently by assuming a reduction of the treatment time. This however, does not reflect the reality. In this model the documentation is dependent on the utilisation of the medical staff, who have a high impact on the overall LoS of the patient if their utilisation is high, or low- or even no impact if the utilisation is moderate. With this scenario it is vital to look at both sides of the argument. The second scenario of employing an additional doctor is used as an argumentative supplement for the first scenario but the results may also be considered on their own.

5.7.1 Documentation Scenario

In the first scenario, it is assumed that the documentation effort of each treatment step is reduced by one minute. For that reason the secondary pathway activities are activated with the following settings: normally distributed with an average of 1 minute and a standard deviation of 30s. Four medical staff types are considered with documentation tasks: nurses, doctors, senior doctors and consultants. As the secondary pathway is connected with the treatment units, the impact is compared with the original average treatment times of the simulation results from these units. The simulation runs were repeated 10 times and averaged.

As in the initial simulation model, the contribution of the documentation is unknown, and can only be retrieved indirectly. In order to obtain these values, the saved times were assumed with the above mentioned settings in the active pathways of the medical staff. With these new settings, the simulations are executed and new overall process times are retrieved for the three treatment units. Bisection method is applied in order to find new parameters for the sub processes within the treatment units. At this point the documentation effort is retrieved directly from the results of the active pathway of the medical staff. Table 5.8 shows the average time of each staff type spent on the documentation and lists the number of arrivals. With this, the numbers regarding the overall effort invested in documentation effort per person and in total can be retrieved. Having identified these settings the documentation times are hence set to zero and the model is executed again in order to retrieve the new process times for the three treatment units.

Table 5.8: Scenario I: Simulated documentation scenario results: estimated documentation effort for different medical staff types.

Medical staff type	Average documentation time [min]	Arrivals of the documetation process	Total effort of documentation [min]	Total documentation effort [days]	Total documentaion effort per person [days]	Projected for a whole year [days]	Summed yearly documentation effort per person [days]
Doctors	1,004	100273	100674,09	69,91	11,65	13,92	83,51
Nurses	1,002	167125	167459,25	116,29	7,75	9,26	138,92
Senior Doctors	1,007	66848	67315,94	46,75	7,79	9,31	55,84
Consultants	1,004	33424	33557,70	23,30	3,88	4,64	27,84
Total working days of documentation effort by staff						**37,13**	**306,11**

Analysing this scenario delivers two results: first, the ratio of the documentation effort to the overall workload, and second, the impact of the reduction on the patients' journey, the passive pathway. The first results show, that the overall medical staff mix within this ED, could save 306 days of documentation work distributed among 24 medical staff members working in the treatment units – this would be a reduction of 5.7% of their overall workload. The second result displayed in Table 5.7 illustrates a comparison of the results from the reduced documentation with the initial setting. It can be seen that the overall process times in the treatment units are not significantly different. This result is explained once the staff utilisation is considered (see Table 5.8): a high impact of the documentation effort would have occurred if the utilisation was close to one, which would have the consequence that the staff pool is empty and that requests for medical staff cannot be fulfilled because the staff are occupied with documenting. As this is not the case, and the utilisation indicates that there are enough idle resources, the documentation reduction has little impact on the patients' journey through the ED even though it has a relatively significant impact on the overall workload. With the workload of 306 days among 24 staff members, it could be concluded that this aid is of equal value as if one additional staff member were to be employed.

Table 5.9: Scenario I: Utilisation of medical staff

Medical staff type	Utilization
Nurses	0,4169
Doctors	0,7507
Senior doctors	0,6412
Consultants	0,2651

Table 5.10: Scenario II: Results for the simulated if one additional doctor is added.

Data origin	Process Stage / Statistical characteristics	Waiting Room (first wait)	Waiting Room (second wait)	Treatment Unit 3	Treatment Unit 2	Treatment Unit 1	Length of stay
Hosiptal records (whole year 2008)	**Target Value for 2008**	**10,61**	**261,05**	**152,94**	**159,57**	**222,42**	**524,03**
	STDev: Target Value for 2008	10,46	246,95	196,83	176,55	300,38	745,53
	Location: Target Value for 2008	4	90	42	70	56	56
Scenario II results (for 2008): One additional doctor	**Total Average**	**10,48**	**199,85**	**132,06**	**137,50**	**115,44**	**436,83**
	Standard Deviation	0,44	14,36	2,51	0,91	4,00	56,36
	Confidence Area 95%	0,31	10,12	1,77	0,64	2,82	39,71
	Confidence Area 99%	0,45	14,39	2,51	0,91	4,01	56,48
	Confidence Interval 95% [Lower bound]	10,17	189,73	130,29	136,86	112,63	397,12
	Confidence Interval 95% [Upper bound]	10,79	209,96	133,83	138,14	118,26	476,53
	Confidence Interval 99% [Lower bound]	10,04	185,45	129,54	136,59	111,44	380,35
	Confidence Interval 99% [Upper bound]	10,93	214,24	134,57	138,42	119,45	493,30
Comparison of results	**Difference to Target Value**	**98,8%**	**76,6%**	**86,3%**	**86,2%**	**51,9%**	**83,4%**
	Error Rate based on 95% Confidence Interval	3,0%	5,1%	1,3%	0,5%	2,4%	9,1%
	Error Rate based on 99% Confidence Interval	4,3%	7,2%	1,9%	0,7%	3,5%	12,9%

5.7.2 Additional Resource Scenario

The next scenario investigates the impact of an additional doctor. The considerations of the model are that the model runs with the initial parameters with which the model has successfully been verified. One additional doctor is facilitated in the model as doctors seemed to have the highest utilisation among the medical staff members.

The results of this simulation run are displayed in the Table 5.10 which indicates a major improvement on the LoS of the patients' journey. The first part of the wait in the waiting room is not affected, as for triaging, nurses are responsible. The second wait however is influenced by the fluency of the system; therefore the queues here are reduced significantly by 23.4%. The new average wait for all patients is reduced by approximately one hour. The treatment units are increasing their throughput rate which leads to major improvements, such as savings in the process times. Figures of of 48.1%, 13.8%, and 13.7% can be observed for units 1 to 3 respectively. The impact on the overall LoS for the patients within the ED could also be reduced by 16.6% which is an average reduction of 87.2 minutes.

5.7.3 Scenario Analysis

The results on the two scenarios deliver new insights for the discussion of the documentation effort which is invested by medical staff. New developments in IT which allow a hospital wide implementation of a PACS or new data input devices, help the medical staff to reduce the time spent on documenting. With these two scenarios, the impact of the implementation of any documentation aid is investigated under the careful assumption, that an improvement would only save one minute of the time invested in documenting. The results deliver a complex answer, as the model investigates not only the flow of the patients, but also the work flow of the resources. The first scenario indicates that a reduction of the documentation effort by one minute per treatment and medical staff, has little or even no impact on the patients' flow through the ED. This is due to the available resources which reduce the total utilisation of resources. However, with regards to the work flow of the medical staff, a reduction in the overall workload of 5.6% could be observed. If we assume a working shift of 8 hours this would mean that each staff member has 27 more minutes available to carry out the other remaining work more thoroughly and can spend some more time with the patients. In sum, the reduction in workload for each staff member is equal to the workload of at least one medical staff member. In order to quantify the "felt" impact of having one additional doctor on board, the second scenario assumed that the model has one more doctor available. Here, doctors are chosen as those who have the highest utilisation degree within this model. The results now indicate that the flow of patients is improved significantly and a patient would on average, leave the ED one hour earlier. These results indicate the importance of saving even a minute.

Following this argumentation scenarios were carried out with the possibility to include active pathways within the *"classical"* passive pathway simulation investigation. With this in mind, it becomes apparent that new relations can be identified and discussed in more detail. In a "one" dimensional simulation which only allows the modelling of primary pathways, the investigation would have either delivered a reduction in the LoS, or alternatively, little or no reduction in the LoS. In cases where a reduction could be observed, the argumentation base for the implementation of a documentation aid would be very low. Indeed opposition could argue, that once they are observing the real ED they see medical staff who are not busy at that particular moment, and who could easily invest their idle time in documenting. A classical simulation model only based on passive pathways is not able to deliver supporting or contradicting arguments for this argumentation, as these relations are not considered within the model. Models considering secondary pathways are more complex and difficult to build and maintain. However, they do deliver a higher degree of transparency regarding the system under investigation and are a real help for decision makers who require a sound understanding before making sustainable decisions which may lead to improvements of the current system under investigation.

This measure would automatically lead to an increase in the quality of care and would place medical staff in the roles for which they were originally trained.

5.8 Optimisation

Finding ways in which to improve the current situation of a system, is the main goal of process simulation modelling. Testing scenarios is one way of finding these potential solutions. Scenarios are alternations to the current setting which are based on an idea from a decision maker. These ideas are routed to the context in which the system under investigation is placed. The decision maker therefore has a picture in his mind of the likeness of its occurrence, for example plans for catastrophes or major incidents which increase the demand for services. Other ideas may be bound to improvements that lie within a certain budget. In other cases it would be interesting to identify the optimum setting of a system in order to see what is potentially possible. These optimum settings can be bound to certain constraints that are defined in an objective function.

Optimisation is one key section to be applied in process simulation. The purpose of optimisation is to alternate an initial set of system parameters and to compare the outcome (also referred to as solution), as well as whether it complies with the objective or target function which is set in the beginning of the optimisation phase. The solution of the next iteration must follow the cost function, if this is not the case, then the solution is discarded and a new alternation of parameters is taken for comparison. This deterministic sequence of trial solutions procedure is commonly applied with classical optimisation methods like gradient or higher order statistics derived from the cost function (Fogel 1994).

Optimisation techniques also benefit from a good layout of the experiments because the numbers of parameters also affect the search for the objective function with the intention either to minimise or to maximise certain outcomes. Optimisation is a technique which is often applied in simulation studies and due to the availability of the executable model and the data provided it is relatively easy to apply. However, the modeller has to choose from a wide range of optimisation techniques and find the technique which is most suitable for his purposes (Fu 2002). Potential optimisation strategies are: mathematical programming (Integer Linear Programming, Mixed Integer Programming, Markov Dynamic Programming), search algorithms (Taboo Search, Ant Colony Optimisation), stochastic programming (Simulated Annealing, Linear Regression, Monte Carlo Method, Knapsack Problem), and artificial intelligence (Neural Network, Genetic Algorithm)).

Consideration of constraints or limits of the system parameters defines and narrows down the search area for the optimisation algorithm. This pairs the convergence of the optimisation method with the objective function. Convergence describes the computational effort to identify the minimum or maximum effort required – at this stage, the modeller should consider that the identified optimum may well not be the global optimum. An encapsulated local optimum may well be identified, of which the optimisation algorithm is "trapped" and unable to move further to the global maximum. This is similar to a marble maze, where a marble is locked in a bump next to the hole into which it wants to go.

In addition to gradient and heuristic optimisation techniques, there are also search algorithms such as taboo search (Guinet & Chaabane 2003), random search, and so forth. One drawback of optimisation strategies applying search algorithms, is that they are often limited in their application and cannot consider constraints or cost functions. To overcome this drawback, whilst utilising the benefits of the search algorithms, one might refer to evolutionary optimisation techniques which aim to simulate Darwins' evolution strategies. Three main approaches are often referenced as evolutionary optimisation: genetic algorithms, evolutionary strategies and evolutionary programming (Fogel 1994). All three approaches incorporate search algorithms, as for example the genetic algorithm clips their genome – a set of input parameters – randomly. The randomness, however, can be led, selected or manipulated, with the purpose of selecting the best genes which can "survive" generations. This selection may have a positive impact on the convergence rate. An overview and introduction of the evolutionary optimisation method is provided by Jin & Branke (2005).

5.8.1 Optimisation of ED-Model

The objective for the optimisation run applied here was to find the staffing level which generates the lowest waiting time for the patients. For that reason the waited minute of each patient is related to a penalty cost of one. If p_w is the waited minute of a patient within the simulation model, then the objective function is:

Table 5.11: Verification of the simulation data with the hospital data

Staff	Upper limit
Cleaners	10
Porters	10
Nurses	25
Doctors	25
Senior Doctors	15
Consultants	10

$$min \sum p_w \tag{5.3}$$

under capacity constraints of medical staffing. The staffing limits are displayed in Table 5.11. The capacity constraints are applied as financial data but the ED is not provided, and therefore budget constraints cannot be applied here. The capacity limits are drawn from the qualitative interviews, where staff are hypothetically asked what they feel constitutes a comfortable number of staff. The result of this estimation is shown in Table 5.11.

The optimisation strategy is provided by the simulation software package, where it is claimed that an evolutionary optimisation strategy is applied. As indicated (Sackett et al. 2007), this description is not sufficiently precise. Indeed as Fogel (1994) discusses, evolutionary optimisation is a categorisation for genetic algorithms, evolutionary strategies and evolutionary programming. The extraction of the code (Diamond 2007) however indicates that a genetic algorithm is applied, which organises the clipping of the genes. The rest of the module programming supports this assumption.

```
void ClipAllGenes(integer pop)
{
integer  gene;

for (gene=0; gene<numParams; gene++)
    if (inputValue[gene])
        {
        if (discreteValues[gene])
```

```
            populationGenesCost[pop][gene] = Int(populationGenesCost[
                pop][gene]+0.5);

        populationGenesCost[pop][gene] = Min2(upperBound[gene],
                        Max2(lowerBound[gene], populationGenesCost[pop][
                            gene]));
        }
}
```

Listing 5.2: Genetic clipping for Genetic Algorithm. Source: (Diamond 2007)

5.8.2 Optimisation Results

The optimisation algorithm applied within this model is a genetic algorithm, which is grouped into the evolutionary optimisation methods. To begin with, the genetic algorithm uses an initial population of possible solutions. In each cycle, every solution is investigated by executing the model several times with different parameters, averaging the samples, and sorting the solutions. The best solution sets of parameters are then slightly modified in order to search for potentially better solutions. The modification is dependent on the outcome of a simulation run and in addition, random alternations are also applied. Every new generated solution is named as a generation. The cycles are repeated until no potentially better solutions are generated. In this case the results of the solutions are converging to a certain value which is then the potential optimum. Like other optimisation algorithms, the procedure of optimisation should be repeated several times in order to be certain of having identified the absolute optimum and not only a local minimum. In this case the optimisation has been repeated seven times and a minimum could be identified of which settings occurred twice (Table 5.13). Another local minimum is also identified, with different staffing levels (see Appendix D on page 340). These two optimisation solutions are identified, whereas Table 5.13 indicates the solution with the smallest amount of waiting time.

Once the optimised staffing level is identified, the model is executed with this very setting in order to investigate the impact of this staffing level. The results of this impact are highlighted in Table 5.13. The first wait is only marginally im-

Table 5.12: Optimal distribution of medical staff within the Simulation-ED tool – based on the simulation results.

Staff	Number
Cleaners	2
Porters	5
Nurses	16
Doctors	25
Senior Doctors	7
Consultants	6

Table 5.13: Optimisation results illustrating the difference to the hospital data [target value].

Data origin	Process Stage / Statistical characteristics	Waiting Room (first wait)	Waiting Room (second wait)	Treatment Unit 3	Treatment Unit 2	Treatment Unit 1	Length of stay
Hosiptal records	**Target Value for 2008**	**10,61**	**261,05**	**152,94**	**159,57**	**222,42**	**524,03**
Optimization results	**Total Average**	**10,10**	**90,30**	**122,73**	**124,85**	**46,07**	**425,56**
	Standard Deviation	0,61	44,85	0,78	0,42	0,79	64,26
	Confidence Area 99%	0,61	44,94	0,79	0,42	0,80	64,39
	Confidence Interval 99% [Lower bound]	9,49	45,36	121,94	124,43	45,27	361,17
	Confidence Interval 99% [Upper bound]	10,71	135,24	123,51	125,27	46,87	489,96
Comparison of results	**Difference to Target Value**	**95,2%**	**34,6%**	**80,2%**	**78,2%**	**20,7%**	**81,2%**
	Error Rate based on 99% Confidence Interval	6,0%	49,8%	0,6%	0,3%	1,7%	15,1%

proved (4.8%), whereas the subsequent processes are improved significantly: the second wait indicates an improvement potential of 65.4% and the process times in the treatment units 1 to 3 are reduced by 79.3%, 21.8%, and 19.8%, respectively. As a result, the overall wait is reduced by 18.8% which is a reduction of 98.5 minutes for the average patient.

This optimum setting is achieved with the staffing level indicated in Table 5.12. It should be noted, that in this setting, the maximum number of doctors is facilitated.

Having identified a local minimum – which can be regarded as the global minimum due to repeated occurrence – the optimum setting is used in order to retrieve the process times and the LoS of the ED. Table 5.14 shows an extraction of a multiple run where the descriptive statistics are illustrated: it can be seen that the overall

Table 5.14: Optimisation: statistical results for the optimum distribution of medical staff within the simulation model.

Statistical characteristics \ Process Stage	Waiting Room (first wait)	Triage	Waiting Room (second wait)	Treatment Unit 3	Treatment Unit 2	Treatment Unit 1	Length of stay
Count	26923	26922	26922	4306	13560	14976	34883
Minimum	0,00	6,51	4,10	46,89	50,54	15,43	9,02
Average	**9,14**	**17,57**	**20,90**	**123,17**	**124,99**	**47,10**	**385,18**
St. Deviation	11,99	14,48	13,44	55,20	42,90	45,50	512,92
Variance	143,76	209,58	180,67	3046,70	1840,03	2070,46	263089,47
Maximum	126,00	276,33	43,06	694,15	837,93	684,67	4915,82
Median	5,51	13,13	15,77	109,79	115,42	35,48	168,03

average LoS is exceeding the 6 hour target by 25.2 minutes. The target set by the HSE considers all patients, therefore the maximum LoS should be considered. As can be seen in Table 5.14 the 6 hour target is significantly exceeded by 4555 minutes considering the maximum LoS.

Focusing on the maximum length of the process times, it can be seen that the ED in the current optimised setting would not be within the 6 hour target at any stage, despite the waiting times being significantly lower in their averages. However, if only the average values are considered then the overall LoS clearly exceeds the target by 25 minutes. The accumulated LoS which excludes the CDU and CCU would result in 94.7, 172.6, and 170.78 for the three treatment units 1 to 3 respectively. If the functional purposes of the process stages are considered, it can be said that the main duties of treatment of the ED is fulfilled after the patients have passed the treatment units. The CDU in particular could also be considered as an advanced service of the hospital as these patients are receiving care during their transition phase to become hospitalised. Thus, if the process of the CDU is withdrawn from the overall LoS, then the ED might potentially fulfil the target set by the HSE. However, this requires structural and procedural changes among the ED and hospital which leads to reconsiderations of the procedures of the ED. Additionally it should be considered that within this analysis the optimised setting is bound to waiting time constraint and does not involve any budget limitations. This is certainly a discussion point but is not considered within this analysis.

With the interpretation of these results, the setting of the ED should also be considered. The process times used for the simulation model were retrieved from a system which has a bottleneck on the hospital admission side. Due to this blockage, the process times, especially in the Clinical Decision Unit are excessively long (average of 900 minutes). Furthermore, the blockages certainly have an impact on the remaining processes as trolleys are placed on the corridor and staff have an additional workload of care for those patients who are awaiting admittance. It is therefore safe to conclude that the ED under investigation would not cope with the 6 hour target, as the data used here reflects a system under blockages. More data would be necessary in order to describe a system which is not affected by a blockage at the exit.

The processing time for the optimised solution takes roughly 252 hours for the identified global minimum, and approximately 92 hours for the local minimum (illustrated in Appendix 7.5), calculated on a 3.1GHz AMD Phenom II quadcore processor (with 4GB DDR3-Ram). Indeed, 5600 samples are calculated with the consideration of 875 cases and 5600 samples. The calculation aborted when the algorithm achieved a convergence rate of 95.17%. The simulation software package only supports a single thread per user, it can therefore only make limited use of parallel processing. A possible solution to this problem would be to assign the processing cores to several users where each core executes a simulation model autonomously.

5.8.3 Discussion about Optimisation Results

Within this field work it is the primary research objective to demonstrate a proof of concept within the new modelling strategy which is best described as "interlinked pathway modelling of limited connected resources". As the new methodology allows generating and maintaining a higher degree of complex models, it was the purpose to demonstrate that optimisation is applicable for simulation models which incorporate active pathways. Generally speaking it should be shown that even with the more complex simulation modelling, optimisation is applicable and delivers potential solutions to the stated problems. The objective function to minimise the wait time, is generally a feasible task if approached in the way demonstrated above. It should be noted however, that the delivered solution is of limited practical use as the financial constraints are not considered. In order to state a practicable objective function more data must be considered as for example, the costs of the resources, potential income. Furthermore, in addition to the budgeting, more details on the staff mix are required: how are the shifts set up, who is fixed allocated to which unit and who is flexibly allocated. Therefore more research is required in order to find an appropriate optimised solution for the ED under investigation.

Chapter 6

Results and Discussion

This field work had two different types of objective: the first one was a theoretical objective which concentrated on proving the workability of the concept, whilst the second concentrated on investigating the practical objectives which are directly applied in the ED. The evidence for the workability of the concept is more thoroughly discussed in chapter 5 (see Page 206) so the focus here is on the application of the concept and of the results derived from the model. Hence the additional detail level will be discussed and in particular how it delivers new insights into and understanding of the system of investigation.

6.1 Results Analysis

The inclusion of active pathways in simulation models demands a higher degree of complexity. This complexity is a challenge for the modeller. A methodology was outlined in this dissertation to design a tool that allows the modeller apply the concept of including secondary pathways with a minimum of additional modelling construction effort. As previously discussed (see chapter 4 on page 144 and chapter 5 on page 206), including active pathways in a simulation model does not only affects the modelling phase in the simulation project, but also the data mining, as well as the verification and validation. Even in the interpretation of the results, the secondary pathways have an influence as they provide additional data which explains certain phenomena.

The aim of this research is to develop Simulation-based Decision Support System which enables an accelerated development of a simulation based solution to improve quality and care at Irish hospitals. DSS has to be flexible to accommodate various sources of variability that occur in healthcare facilities. Derived from this aim, the resulting five objectives can be split up into theoretical and practical objectives.

The results analysis in this chapter will be structured around the objectives outlined for the thesis. The first three objectives focused on the derivation of the DSS. These comprised;

1. To examine current practices in A & E department in order to address different sources of variability within the department;
2. To develop or adopt a comprehensive modelling technique to help in capturing the dynamics of the system under investigation;
3. To construct ready-modules into a library form in order to speed the modelling process;

These three objectives are linked to the novel modelling approach MPPM and FRA that facilitates the modeller to construct simulation models where intersected pathways are required to be represented. A comprehensive and thorough description is provided in Chapter 4 which provides a description that enables the modeller to capture the variability of an ED. In addition the modeller is equipped with ready-modules that speeds up the modelling process.

The latter two objectives relate to the field work phase;

4. To define bottlenecks and system constraints in order to develop corrective actions (i.e. strategies and plans);
5. To develop an optimisation capability to be integrated into the DSS for better decisions such as stochastic uncertain environments.

Bottlenecks and system constraints can be retrieved from the system description in section 5.2 on page 207 and a thorough description of evolutionary optimisation techniques that are applicable for simulation models that are considering MPPM and FRA is provided in section 5.8 on page 256.

6.1.1 Theoretical Objectives

Examination of Current ED Practices

The current ED practices are examined and described in various ways: First, a general description of the ED itself is provided which describes the patient pathways and the patient cases that are treated within the ED (see section 5.2 on page 207). Second, the processes that are obtained from the quantitative and qualitative analyses are displayed in a comprehensive process flow map (see Figure 4.4 on page 171) and in an IDEF0 booklet (see Appendix E.2) that thoroughly displays the activities of the ED under investigation in various hierarchical levels. These descriptions display the routing of the patient as well as the staff types and their work flow.

Comprehensive Modelling Technique

Within dissertation a holistic DSS is developed and described. It provides a novel approach which allows easily constructing simulation models that allow considering several pathways that are interlinked and dependent on the same resources, here described as Multiple Participant Pathway Modelling (MPPM) and which additionally facilitates the modeller to represent the Flexible Resource Allocation (FRA) within the models. The modelling technique is explained in chapter 4. The core of the modelling technique is an algorithm which allows speeding up the creation of the MPPM and FRA models. This algorithm is explained in a pseudo code (see section 4.1.3 on page 166), so that any modeller is able to benefit from the automated model creation as long as the requirements to the simulation software packages are met (see section 4.1.3 on page 160).

Ready-Modules

To complete the description of the modelling technique, ready-built modules are provided for data mining and for modelling MPPM and FRA. Data mining modules consists of tool sets that provide data- filtering, processing, and conditioning, while the modelling modules enable the modeller to build models that include active and passive pathways. The modelling modules are available as library blocks and are ready for use within the software environment, that meets the specified requirements (see section 4.1.3 on page 160). The source code, the library modules and the description of its application are obtainable from the included DVD. A short version of its description is provided in the Appendix 7.5.

6.1.2 Practical Objectives

In order to consult the ED on improvement measures as for example the introduction of a documentation aid or employment of an additional doctor. The measures are described in the analysed scenarios that are here described as practical objectives which meet the requirements of the third objective. The bottlenecks and system constraints are a requirement to build the simulation model as explained in chapter 5.

The in section 5.8 introduced evolutionary optimisation strategy has proven itself as a feasible approach which can be applied in simulation based DSS that are considering MPPM and FRA.

First Practical Objective: Providing KPIs

One practical objective is to provide a tool which can help to understand and investigate the current system of the ED in the SVUH. This understanding is easily conveyed by the GUI which provides animations and graphs. These animations and graphs display the queues and tables which deliver KPIs equivalent to the KPIs which are of interest to the management of the ED under investigation. Having identical KPIs and similar data sources provides trust in the model, and the user understands immediately how to interpret the data of the simulation runs. However, in order to not overwhelm the user with information, the KPIs reflect only the main flow indicators of the passive pathway (patients' journey). The GUI on the other hand can easily be extended to provide data from the active pathway. At the end of a simulation run, the same set of data is stored in a spreadsheet similar to the one provided by the hospital. Here, all of the data analysis tools are then available to retrieve any hidden information.

Second Practical Objective: Scenario Analysis

The testing of the scenarios is one part of the practical objectives stated at the beginning of this chapter. The introduction of a documentation aid for medical staff should be evaluated and the potential impact of this aid should be assessed. A potential documentation aid could be hand held tablet PCs, which allow medical staff to enter and evaluate data in the presence of the patient. Another documentation aid would be speech recognition software, or a implementation of a hospital wide PACS, which allows to access medical images from any suitable PC within the hospital. Implementing documentation aids are costly – the decision makers therefore have to consider the potential impact of the modifications. For that reason, the first scenario investigates the impact of the reduction of the documentation effort by one minute whilst the second assesses what the outcome would be of employing an additional staff member such as a doctor.

The results of the reduction of documentation effort for medical staff have led to different considerations: first, the process and waiting times for the patients are not significantly affected or reduced, and second, in an average daily shift of 8 hours 27 minutes staff workload is reduced meaning that they are available for other tasks.

The relation between these two considerations is easily explained as the reduction would only show a high impact if the medical staff were being sufficiently utilised. However, as the highest average utilisation is smaller than 75%, it can be concluded that a member of staff is always available to step in and complete the task of the staff member occupied with documentation. Providing this kind of explanation in advance is extremely valuable and contributes considerably to the concept of applying active pathways to a simulation model with MPPM. Even though that the impact on the patients' journey is minor, it is calculated that the reduction in the workload of the entire staff is equivalent to adding one additional staff member. The second scenario assesses what the impact would be if there was an additional staff member available. As the workload relief exceeded the workload of one staff member by the ratio of 1.3, an additional doctor is provided for in the simulation model as this staff position had the highest average utilisation figure. The results of the simulation model show that having an additional doctor available makes a considerable contribution to the LoS, which is reflected in a reduction of 16.6% for the LoS. The average amount of time that a patient spends in the ED is lowered by 87 minutes to 437 minutes.

Considering the impact of having an additional doctor available, it can now be estimated how the one minute of relief contributes to the daily operations of the medical staff. An impact similar to that of the second scenario can be seen in the first scenario if the saved workload is spent on the patients: having reduced the workload by 27 minutes each day, staff can perform other duties with more care and awareness thus preventing potential errors. Despite the fact that only one minute is saved during the task of documentation, this allows staff to pay more attention to the patient and his / her needs. This conclusion is of course speculative, but on the other hand it shows the potential benefits of having data retrieved from the active pathways: new interpretations and new insights are now available to aid in finding explanations for the phenomena within a system. In this example it can be demonstrated how quantified results are turned into qualitative data by assuming that the saved workload will be invested in a higher quality of care for the patients.

Third Practical Objective: Optimisation

In addition to the practical objective, a theoretical objective is also included with a view to proving that optimisation is even applicable to a system which includes dynamics of those containing active pathways modelled with MPPM. The motivation behind the identification of the best staffing level is to evaluate whether the current ED would achieve the 6 hour target set by the HSE. The 6 hour target was introduced in January 2009 and states that *"a total waiting time target of 6 hours was set from the registration of the patient in the emergency department to admission or discharge"* (Buckley 2009, p. 10). This is of special interest for the management of the ED as this target is apparently very ambitious, especially when it is considered that the average LoS within the ED is 8 hours and 44 minutes with an observed maximum of 3 days 21 hours and 35 minutes; a figure retrieved from the hospital records. Therefore it should be identified whether, regardless of costs, it is at all possible to meet this target with the current setup and if so, what measures are needed to achieve this.

6.2 Discussion

Simulation is well positioned as an effective means to evaluate the impact of changes in strategy and/or processes on system performance. This is done through various "what-if" test scenarios, either in industrial or servicescape applications (Cochran & Bharti 2006*b*). A growing number of simulation software packages have provided the modellers with more simulation capabilities to extend their modelling functions and enhance optimisation processes. However complex the functionality of the software packages is, it is important to enhance the concept of simulation modelling. Process simulation, covered by DES, considers the concept of active and passive pathway modelling such as MPPM, and provides a concept where the item, product or patient, is processed and enhanced by resources and production units. In these models, the effects of shortages and blockages can be simulated due to limited and shared resources. Production units however are considered to be available. In healthcare service simulation, however, the production units are the medical staff who are involved in their very own procedures. While treating the patient they are not bound directly to that patient. This environment and setting thus demands a new concept of modelling which allows the inclusion of active and passive pathways and which is described here as the *"interlinked pathway modelling of limited connected resources"* or simply MPPM. Here, the inclusion of active pathways is proposed and described within the framework that is illustrated in the fourth chapter. The first field work application is introduced in the second half of the fourth chapter and can also be considered as practical proof of this concept. The field work has focused on several application fields which deliver results on the transparency of the system under investigation, identify scenario outcomes, and test optimisation strategies. After the summary of results, the subsequent discussion indicates the value which is obtained from the additional insight provided by the concept of secondary pathway modelling.

6.2.1 Limitations due to Complexity

It is a common recommendation among process simulation modellers to avoid any unnecessary complexity and to keep the model as simple as possible by focusing on the negotiated objectives (Vissers 1998, Musselman 1998). Keeping simulation models as simple as possible is important as the modeller might otherwise waste time end effort on details which only make a small contribution to the outcome and precision of the model. This measure of reducing complexity is a common and necessary measure in order to provide an insightful, administrable and maintainable model for the purpose of investigation. However, as indicated in the literature review, healthcare simulation models previously used and applied show that models are limited in the degree of complexity and rarely consider the overall complexity of the system under investigation. These models however fulfil their purpose as deliver insightful results which are validated and verified through the hospital data records. By focusing on their flow paths it can be seen that the simulation models are focused on the pathway of the patient and regard the doctors and nurses as granted and available resource – scheduling of staff is under represented among healthcare simulation models. However, even those in charge of staff scheduling, only limit the resources to a certain time but do not imply a pathway only for staff. The fact that an active pathway is not included in these models has been derived from observations within this research. To the authors' best knowledge such models describing the interaction of different pathways have not yet been applied.

6.2.2 Novel Modelling Approach

Introducing the concept of active and passive pathways in MPPM is certainly applicable where resources or production units are flexible and allocated to the demanding workstation. Flexible resource allocation can be observed in servicescape, where services are allocated to customers who are stationary, for example in healthcare. The resource, here medical staff in the ED, would walk to the cubicle where the patient is located for treatment. The resource will therefore dynamically be routed depending on the demand for the resource. In the present dissertation this concept is described and named as flexible resource allocation (FRA) and multiple participant pathway modelling (MPPM). In order to allow simulationists to model such a dynamic environment a FRA framework is developed and explained. The FRA framework also supports active (secondary) pathways, especially as these resource units can be bound with activities which must be accomplished according to the work flow description. Including such secondary work flows however is challenging for the modeller, because the resource is not only bound to one stationary workstation, instead it is demand driven and therefore flexibly allocated. This flexible routing increases the effort to administrate, create and maintain such a model. In order to provide guidance and support for the modeller, a procedure is proposed which is applicable in simulation packages which fulfil certain requirements. It is also applicable to those which program a model within a programming language.

The algorithm described within the FRA framework delivers multiple sequential pathways that are connected with the requested amount of resources. The pathways of the resources are hence extendable in order to include the activities that describe the work flow of the resource. The algorithm is translated by making use of the programming interfaces within the simulation packages that allow executing automated modelling – the models are hence drawn by the algorithm described in the fourth chapter. Having executed this automated modelling it becomes key to decreasing the effort which is usually required in order to build such complex and dynamic models. On the downside, the modeller would first have to implement a FRA-Block in his applied simulation package, which requires programming skills and provides an additional challenge. With a programmer at hand, this algorithm would need only be implemented once and various complex models can be constructed just by providing the model property parameters, such as number of resources, number of process chains, and number of process steps.

6.2.3 Fieldwork as a Proof of Concept

In order to prove this concept it is applied in a fieldwork situation where the task is to identify the amount of documentation effort that is required for medical staff in the ED. For this task both pathway groups must be considered: first, the pathway which drives the demand – the patient pathway. Second is the pathway which describes the work flow of the medical staff. As the proof of this concept is embedded in fieldwork, other objectives are also regarded once the study is launched such as providing a detailed insight into the system under investigation by providing KPIs, and by trying to ascertain the probability of targets set by the HSE being accomplished.

As indicated in the framework the fieldwork confirmed that applying the concept of MPPM demands more data as here there are two aspects of pathways to be considered. As quantitative data may not be be able to provide all of the information required to build a representative model, further qualitative data may be needed. During this fieldwork, observation of the staff work flow and interviews provided the necessary initial data. This data was later interpolated with the model and the hospital records in order to identify process times for certain treatment steps.

Conceptual modelling aided the modeller, especially once the resources were allocated to the treatment units and processes. A two fold conceptual modelling approach was used here. The first method focused on the flow of the patient and their routing, displayed in a flow diagram, while the other displayed the distribution of the resources for the detailed processes, illustrated in IDEF0 diagrams. These conceptual models were required to aid the modeller with the creation of the actual simulation model. The model then needed to be built in a way which matched the first and second hierarchy level of the conceptual model. Additionally the model needed to be built around the hierarchy block which represents the flexible resource allocation. This FRA-block is created in a separate simulation model automatically and hence is included in the actual simulation model. While inserting the FRA-block, final adjustments are required before the simulation model can be executed.

For the verification and validation of the model, the input data from the hospital record was compared with the results of the simulation model. The comparison of both data sets – hospital data with the simulation results – delivered a high correlation between both sets. As this field work is partially a proof of concept, it is therefore important to highlight that the simulation model achieved trustworthy verification and validation results.

6.2.4 Results on Decision Analysis

The main application field for the concept of MPPM has been to evaluate and investigate the scenario where documentation aids are implemented, for example PACS, hand held tablet PCs for instant bedside documentation, or speech recognition. Here the strength of the concept of MPPM is becoming visible because the patients pathway (passive) would not indicate a major improvement to the LoS, while results drawn from the work flow of the medical staff (active pathway) indicate a high relief on the overall workload. This saves time and effort which can then be contributed to the patients, who will recognise this as an improvement in quality of care.

Of special interest was to investigate whether the current setup of the ED would allow meeting targets set by the HSE which state that each patient should not stay longer than 6 hours within the ED. In order to retrieve a setting which would identify minimum waiting time for patients, an evolutionary optimisation algorithm is applied. This setting which leads to a minimum waiting time for the patients, is hence investigated and the results show that the targets are not achievable without major restructuring of the ED. A possible solution would be to move tasks which are hospital related and make them the responsibility of the hospital administration, e.g. CDU. However, here it can be seen that the data provided creates limitations to the interpretation of the results as the data was obtained from an ED which has a constant blockage on the exit to the hospital ward; something which may have an impact on the process flow. This impact is difficult to retrieve and more observational data may well be required to draw a clearer conclusion.

Chapter 7

Conclusions and Future Research

7.1 Introduction

Process simulation modelling enables the replication of general work flow patterns in conjunction with activities and resources. In manufacturing, Discrete Event Simulation (DES) is highly appreciated as a decision aiding tool; it supports decision makers by determining and revealing unseen relationships and further allows the investigation of "what-if" questions. One of the major advantages of DES is its flexible approach which enables its application in wide areas, ranging from manufacturing, over to servicescape and through to science. Its flexible approach leads to new ideas for constructing simulation models in order to better adapt to the investigated systems. In principle, the DES maps a primary work flow and assumes that resources are more or less available, depending on constraints or given limitations.

Before this research commenced, the issues concerning the Irish healthcare system were well known. In order to design an appropriate Decision Support System (DSS) for healthcare facilities, these issues needed to be clarified and allocated to the problems' source. An understanding of the mechanism of healthcare in general is developed and systematically structured for integration into a novel approach to design a DSS, regarding the complexity and dynamics of a system. For that reason, solution methods must to be identified that are capable of answering the desired questions of decision makers. The DSS is to be designed in a way that it can be easily transferred to other healthcare facilities which show those characteristics, whilst still contributing to the dynamics and complexity of the healthcare system.

A motivation to deliver a DSS for emergeny departments (EDs) was the severe condition of Irish EDs with a high utilisation between 95% and 99%, and long waiting times. According to the Emergency Task Force Report (Health Service Executive (Health Service Executive (HSE) 2007) – issued by the Health Service Executive (HSE) – 57% of all patients wait longer than 6 hours, with some (39%) waiting for longer than 12 hours (more details are provided in the Literature Review in Section 2.1.4 on Page 34). A DSS based on DES and optimisation therefore appeared to be an ideal solution method in order to provide decision makers with information and insight into their system, thus allowing them make decisions based on sound information.

Identifying improvements especially in a complex topic such as healthcare is a challenging undertaking. The higher the complexity of an investigated system, the more data is required for adequate decision making. Healthcare decision makers, responsible for investments which facilitate sustainable improvements to a healthcare facility, commonly apply statistical or mathematical models to evaluate improvement potentials. In the current climate, healthcare in general is forced to apply the best possible service at a minimum of cost. Due to this demand, decision makers strive to identify any investment potential which offers an increased efficiency of their service. Implementing a homogeneous information technology within their services, such as a Picture Archiving and Communication System (PACS) is a common approach to shorten wait times of doctors for patient data which has also an impact on the overall process flow. Such information systems contain a lot of patient process data, which can be facilitated in tools for decision making. One tool for decision makers – successfully integrated in manufacturing and facing higher acceptance in healthcare – is process flow simulation. Processes can be mapped according to the work flow within the investigated facility and investigated for improvement potentials by testing "What-If"-scenarios. With the increased acceptance of DES and its application in healthcare, almost 2500 research studies are recorded (Harzing 2010) in the last 15 years and the trend is increasing in this area.

However, the process flow models applied consider the process flow of one party, the patients. However, a process model which included pathways from several parties, such as patients and medical staff could not be observed to the best of the authors' knowledge. Ignoring the relationships among several participants is done for several reasons: first, modelling such systems is complex and the improvement in the accuracy of the model is difficult to forecast, so that the modeller is unsure whether it is worth the effort, and second the data availability. In healthcare facilities which do not have a homogeneously distributed HIS, might struggle to provide the necessary data. However, building representative models with DES requires a vast amount of data. Process simulation as such would benefit from the introduction of HIS in healthcare facilities and eliminate the second drawback.

Including active pathways in passive pathways automatically increases the complexity of the simulation model, which usually increases the modelling effort of the simulationist; this effort is significantly reduced here by the Flexible Resource Allocation- (FRA) block which is designed after the FRA-framework; this is illustrated in the 4th chapter. The FRA-Block reduces the modelling effort by automatically executing the tasks which would be highly repetitive and potentially confusing for the modeller. After having applied the FRA-Block, the modeller is hence equipped – after having applied minor adjustments – with a model that includes secondary pathways. Interpreting simulation results is hence possible under the consideration of limited and connected resources. This is a common sight in the servicescape. An abstract discussion of the workload and the utilisation of human resources in such a flexibly allocated working environment is provided in the discussion section 4.3.3 (Thorwarth et al. 2009).

Reducing complexity within a simulation study is a common undertaking and it is essential to focus on the data that impact the results of the simulation. These measures may apply to the amount of data needed or to the routing of the model itself. The objectives for the simulation project deliver the frame in which a reduction of details is applicable, for example it is seldom of benefit to investigate the duration of disinfecting a needle, while the objective is to identify bed utilisation. However, some objectives require a high degree of complexity which might either address the routing or the data requirements. Within this dissertation, an opportunity is provided to decrease the effort invested in building models which capture the concept of secondary pathways. The complexity of the model is thus not reduced, but yet representative complex models are built without the potential to inflict structural errors within the routing of the model.

7.2 Conclusion to the Research

This dissertation discusses the need for an extension to the process simulation modelling approach, and delivers for the concept of including secondary pathways, a framework that extends and considers the flexible resource allocation. Additionally guidance and instructions are provided in the form of an algorithm so that any modeller is equipped with a recipe which enables *"interlinked pathway modelling of limited connected resources"* with a minimum of additional modelling effort.

Thus far, to the best of the authors' knowledge, no description of a simulation model has been retrieved which considers dependencies of several interlinked work flows. This new concept considers active and passive pathways which are dependent on the utilisation of the resource by interacting with the primary (passive) pathway. The concept is derived from the observation of healthcare. There it could be seen that the doctors and nurses had to follow their own procedures while interacting with the patient. The results provided in chapter 6 indicate that the observed concept and the conversion is applicable. This concept delivers new insights regarding dependencies of resources and furthermore allows a detailed outlook of the impact of new policies; something which has been shown by the evaluation of documentation relief. Healthcare services are therefore a prospering application field for this concept, and with the aid of the FRA framework, the complexity issues are tamed by providing the modeller with guidance and instructions on how to model such a complex environment with minimum additional effort.

Healthcare would not be the only application field for this concept, the servicescape in general, where staff interact with customers may be a potential application. Another potential application is tourism for example where tourist companies organising entertainers for their tourist groups which are allocated at different locations. Here, the presence of two several pathways can be observed: first the one of a tourist group which wants to be entertained throughout their holiday (would then be the passive pathway), and second the pathway of the entertainer (would then be the active pathway) who must make preparations and travel to the location of a certain tourist group. If simulation is applied here on just one pathway, then the dependencies are missed and this would potentially lead to non representative results.

For this reason, the research methodology for simulation models was applied as discussed in chapter 3. It was applied with the current consideration of the modification which would allow an application of the concept of the *"interlinked pathway modelling of limited connected resources"* as proposed within chapter 4. This field work is therefore divided in several sections:

- Identifying the objectives;
- Retrieval and analysis of data;
- Development of a data analysis tool;
- Constructing conceptual models;
- Applying the FRA-block for the building of the actual simulation model;

- Verification and validation of the model;
- Designing a graphical user interface (GUI) that yields animation and provides KPIs;
- Testing the model in order to find answers to the clinical objectives;
- Evaluating results retrieved for their application and relevance.

These sections are similar to the research methodology for simulation models and mirror the applicability of the concept which implements FRA and Multiple Participant Pathway Modelling (MPPM) in the discrete event simulation modelling; the academic objective within this field work. Including active and passive pathways in the DES provides new possibilities to construct, analyse and interpret simulation models. As simulation modelling demands a sound preparation for data retrieval, the simulationist should consider in advance which data is available and where it can be retrieved from. Quantitative and qualitative data analysis methods may be required depending on the depth and detail of the model.

The results of the simulation model delivered transparency in the form of providing animated queues and continuous KPIs during the model execution. Diagrams support the graphical impression for the model so that the user can retrieve all relevant information regarding the status of the model at a glance. Decision makers can therefore retrieve additional information from the model which increases the information basis and thus creates more confidence in the decisions.

The workability of this concept is illustrated within the field work which takes place in an ED of the St. Vincent University Hospital (SVUH). The results deliver additional insights, especially where the introduction of documentation aids is considered. As two pathways are considered, two results are discussed: first the impact on the patients' pathway and second, the impact on the work flow of the medical staff. The results obtained here provide an insightful impression of what the implementation would provide as a benefit. Simulation models only focusing on the patients' pathway would not capture the issue of the staffs' utilisation. Simply put the lower staffs' utilisation the lower the impact of the documentation aids for the patients flow. This relationship would simply be ignored, and models which simply assume a reduction in the process times of medical staff, would produce false recommendations for the decision makers. In other words: the decision makers would be highly disappointed not to see the promised impact after having invested a lot of resources for the documentation aids.

The purpose of the field work is firstly the proof of concept and on the other side, a testing ground for the simulation model itself by applying studies to find answers to system relevant questions for the ED under consideration. These questions are summarised in clinical objectives which range from delivering an understanding, over to test scenarios, through to testing the setup of the ED by identifying and investigating the best possible setup.

The illustrated field work has accomplished several tasks. First, it demonstrates a proof of concept for the *"interlinked pathway modelling of limited connected resources"*, second, it answers clinically relevant questions by providing more detailed information. This is done through regarding the complexity and the dynamics of the ED. Finally, it provides a guidance and a toolset which allows modellers to apply a higher degree of complexity, if it is relevant for servicescape modelling, without overwhelming the simulationist with additional administrational and maintenance work.

In general, this framework delivers a valuable contribution to theory and practice. Indeed within this dissertation it has experienced its first baptism of fire through its application to the investigation of a highly utilised ED of an academic hospital. Having applied this framework, a simulation model is generated which delivers a detailed insight into the ED and provides answers in a multi perspective thus providing invaluable information for decision makers.

A common argument within the process simulation community is that simulation models should avoid unnecessary details that lead to an increased complexity. In this case, the FRA and MPPM increases the models complexity significantly, but in case of application in servicescapes, the increased detail levels are needed in order to illuminate relationships of dependencies which were not investigated before. Therefore, with the right toolset at hand, such as the FRA-block, and the guidance provided, simulationists and users can benefit from the extended complexity.

7.3 Contribution to Knowledge

The objectives for this research are twofold: one objective is to provide a framework which allows the consideration of flexible resource allocation; something which can be found in the concept of MPPM. This framework has to be consistent with the recent simulation research methodologies. The second objective is to prove the validity of this framework and of the concept by applying it in a field work situation which is in need of such a framework. For that reason, the initial identified objectives are split up in two categories: theoretical and practical objectives (as highlighted in section 6.1 on page 265). The theoretical objectives are covered by the proposed framework for the DSS and the practical objectives are accomplished with the field work.

The field work investigates the ED of an academic teaching hospital with the following objectives: First, providing a tool that increases the transparency of the system and enhances the understanding of the system under investigation. Second, to evaluate the scenario which delivers estimations regarding the impact of the introduction of a documentation aid, and third, to indicate whether the 6 hour target set by the HSE can be achieved with the current setup. The first objective is accomplished by providing a framework which allows simulationists to implement the concept of active and passive pathways in the simulation model. The framework therefore delivers a procedure which facilitates the modeller to program an automated mapping of the processes, according to an algorithm that can be translated in any simulation software package which fulfils the requirements. The complex routing is therefore done by the programmed FRA-Block, which only requires the main parameters such as the amount of shared resources, the number of linear parallel process chains, and the treatment steps within the process chains. The common source of error in complex models could thus be reduced to a minimum. This framework is consistent with the simulation research methodology. Example models, source code, libraries and modules are provided in the Appendix on the DVD. These can be used as a reference for future models that replicate the concept of active and passive pathways.

To broaden the scope of this project it is the aim to generate a DSS in a general manner, which allows the concept to be transeferred to other application fields. For example, in order to generalise the DSS to other healthcare facilities than EDs, the DSS must be designed in modules that are general enough to be transferred, but yet specific enough, to reflect the dynamics of healthcare services. Thereby, the DSS is divided into several parts, of which one module handles the data- filtering and processing, another constructs the model in a semi automated way, and finally provides a module which aids the verification and validation of the model and the tested scenarios. There are two main deliverables within this thesis: first, the framework presented in this thesis is addressed to other simulationists who model healthcare facilities, and second, the DSS developed here investigates within the applied fieldwork the ED of the SVUH in order to provide information for its future development and for decision makers.

Motivated to help decision makers in finding solution on a sound information basis, it is the aim of this study to provide a comprehensive DSS that delivers a novel detailed approach and that respects the complexity and dynamics of healthcare systems. As well as this, it also aims to facilitate other researchers and simulationists who wish to widen the potential of integrated solution methods.

7.3.1 Theoretical Objectives

It is intent on proving the validity of the framework within the field work, and follows the common methodology for simulation research under the considerations of this framework. With this measure, the concept could not only be approved, but also demonstrated to be valuable for practicable purposes. For this reason, the three objectives are investigated; something which is part of any simulation research.

The simulation model, built according to the here introduced framework is able to provide additional insight and transparency which increases the understanding of the system for the decision makers, by delivering KPIs, animation, data and graphs – integrated in a GUI. The most significant proof of concept is, however, the investigation, which considers an investigation on two dynamically interlinked pathways: identifying the impact of the reduction of documentation effort for medical staff while treating the patients. Here, two pathways must be considered, the pathway of the patient is on the first pathway, while the work flow of the medical staff is the second pathway. These two pathways are dynamically connected, as the medical staff working are demand driven. The results of this investigation deliver two perspectives: firstly that the patients' journey is not affected if the relieve of documentation effort is one minute, while staff would experience a relieve of 27 minutes on average per working shift which can be invested in providing better care or more attention to the patient.

Another objective aims to illustrate the application of optimisation by identifying whether the ED would be able to accomplish the 6 hour target set by the HSE under the current setup. For that reason, the staff level setting is identified, which delivers the minimum waiting time for the patients by applying evolutionary optimisation strategies. The optimised staffing delivers results which indicate that the ED would not be able to accomplish the current target, without structural changes, and would need to shift responsibilities to the clinic.

Within the field work, it is shown how the concept and framework is applicable and feasible solutions for modelling are provided. To supplement the practice with some theoretical considerations, it is illustrated in the following sub chapter how the concept can also be fitted within the queuing theory. Within this illustration the effects on utilisation of flexibly allocated resources are explained and how these can be expressed in a mathematical description which can be embedded in the queuing theory.

After having applied the field work with the developed framework, its applicability could be clearly seen as well as its value in delivering additional insights into the dynamics of a healthcare facility. The most important value is delivered once the objectives begin to affect several pathways, which are impacting each other following the concept of secondary pathways. This concept is observable in servicescape and the application of this framework would enhance DES to deliver representative solutions under the consideration of the dynamics within the system.

Additionally, a guideline is provided for other simulationists wanting to design a DSS based on simulation and optimisation inheriting features like FRA and MPPM. For this purpose these identified mechanisms are discussed in regard to their modelling complexity, while applying them in a simulation model. To reduce the modelling complexity an automated modelling procedure is proposed, that helps in the design phase of models integrating FRA and MPPR.

7.3.2 Practical Objectives

The clinical objectives however are first needed to give the simulation model a purpose, and secondly to provide answers to clinically relevant questions which are in the interest of the hospital management. The ED under investigation, even though it appears to be well structured when visited, has severe problems according to the hospital records: average waiting time of more than 4 hours and Length of Stays (LoSs) which are exceeding the target set by the HSE by nearly 3 hours (total LoS $8\frac{3}{4}$ hours). In order to ease the situation and to put a relieve onto the ED under investigation, the impact of documentation aids is evaluated. In addition it is demanded that the simulation application should increase the transparency and thus provide an understanding for the dynamics within the ED.

In order to increase the transparency, the verified model is equipped with a GUI that provides animation and KPIs. The GUI allows the user to alter parameters like staffing levels or process times during runtime and allows visual tracing of the behaviour of the system according to the applied changes. Second the GUI provides graphs that inform the user about the development of queues and the KPIs deliver insight about the resources' utilisation. The simulation model with the GUI allows the user to virtually explore the system and learn about its behaviour. This feature increases the understanding of the system for the user and decision maker, so that the decision maker has a sound information basis for future decisions regarding the system.

Another clinical objective is to find answers to whether a documentation aid would have an impact on the process flow and to describe how. As the model considers active and passive pathways, the explanation and the answer to this question is twofold: the first result, which focuses on the patients pathway indicates that there is little or no improvement to the LoS. However, as this model allows an addition evaluation of the work flow of staff, it can be presumed that there is a significant relieve on the work flow of staff. This reflection is possible because two interlinked process flows are investigated – patients flow and the work flow of medical staff. A model representing only one of these flows would not be able to present and forecast the outcome which will be observed after the implementation of results.

The third objective involved a test whether the ED, with its current setup, would be able to fulfil the 6 hour target set by the HSE. An evolutionary optimisation algorithm was used in order to identify the staffing level which allow a minimum waiting time for the patients. Having identified this staffing level, the model was executed and analysed whether the maximum LoS would be within the 6 hour target. The maximum times still far exceed the 6 hour target and even the averaged value of the total stay would not fulfil this target. The ED would therefore consider structural changes which would conclude that duties and tasks requiring transfer to the hospital such as the CDU should be set under the responsibility of the hospital. If the CDU were to be withdrawn from the ED then the average LoS of the patient would accomplish the 6 hour target. This recommendation is deducted from data of an ED which is chronically suffering from a blockage at the exit for the admittance to the hospital. Further data and additional considerations leading to further adjustments to the model, may be necessary in order to provide a more detailed view on the impact of changes. These are necessary to provide a forecast of the new setup ED.

7.3.3 Deliverables

In consequence to the objectives the following deliverables are provided:

- *Literature Review*: Analyses of the current simulation application in healthcare.
- *Guideline*: Delivers a structured guideline, to build modules and libraries that represent the dynamic workload allocation within a flexible dynamic working environment. This guideline should be applicable as a rulebook.
- *Modules and libraries*: Designs ready built modules and libraries that comprise:
    - Data mining:
        * Filtering

        * Processing
        * Conditioning
    - Libraries applying FRA and MPPM
    - Tool set applicable to verification and validation

- *Field work*: Proves the validity of this concept as field work tests the usability of the modules and the appropriateness. This field work is applied to an ED located in SVUH. Within this study the following clinical objectives are stated:
    - Provides a DSS for analysis which is able to deliver Key Performance Indicators (KPI) and allows the retrieval of an explanation for the dynamics within the ED.
    - Test of the following scenarios:
        * Scenario I: Identifies and explains the impact of the introduction of documentation aids such as PACS, hand-held tablet PCs, or speech recognition.
        * Scenario II: Illustrates the impact of employing one more staff members.
    - Applies optimisation to test and illustrate whether the target set by the HSE of keeping the LoS for patients below 6 hours, is achievable with the current set up of the ED under investigation.

7.4 Research Limitations

It has to be regarded that certain data cannot be obtained by the hospital records, which hence limits their applicability. For example, it is impossible to state whether a certain patient arrived via ambulance, walked-in by himself, or had been referred by a GP. Also unknown is when a change in the triage level has occurred; only the first entry is recorded. Another issue is that the time for the lab is not retrievable from the hospital records. If a patient went for a medical imaging, this record is not retrievable either. As patient waiting during the processes is unavoidable, and even necessary in some cases, there is no statement regarding the actual process time. The process times presented here are a sum of waiting time and several individual processes. The data retrieved from the hospital therefore must be considered with care and supplementary data is necessary from the interviews.

Neither the quantitative data nor the qualitative data is able to reflect a completely truthful picture of the current situation within the ED. The quantitative data contains false or misleading entries, and the qualitative data is bound to the subjective impression of the interviewee. However, the modeller is challenged to filter out the false data, by eliminating outliers, or considering redundant information and to consider that subjectivity can be minimised by involving more interviews. Due to the previous factors, it is important to note the factors which are influencing the data in a negative way. It is therefore essential to create an awareness of these factors which hence enables the modeller to consider the right techniques in order to achieve a sound and representative set of data.

7.5 Future Research

The research provided within this dissertation indicates future research potential in various ways: first, the generated models that cover the concept of secondary pathways can be investigated more thoroughly by finding mathematical descriptions following the discussion section 4.3.3 on page 199. Queuing theory is illustrated to be applicable for the concept of secondary pathways, but identifying the impact of its dynamics would offer a new area of theoretical research. Second, finding an optimisation strategy that is suitable for finding solutions with minimal computational effort would be another research interest. Finally, the application in various domains – even outside servicescape – would deliver new insights into the framework and further future refinements which would improve the accuracy of modelling dynamic interlinked systems.

The next steps with regards to continuing this research would be to find a generalisation of the libraries and modules so that these could be easily transferred to other healthcare application fields, as indicated with the consideration of application in the ICUs. This generalisation would then allow building a hospital wide simulation, with several sub domains and additionally a comparison of several research studies would hence be applicable.

In this context it would be worth testing and seeking opportunities for the integration of such a simulation tool in a HIS. Here the data would already be contained and planning on basis of operational research would hence be applicable.

Another worthwhile investigation would be to find a viable solution for the animation which would be able to display the parallel tasks of the active and passive pathways. This would thus increase the transparency significantly and non trained users would understand the mechanism of the model more easily. Training on the model would then be available.

Another research opportunity would be to identify an optimisation method which is best suited for the dynamics of the system. A fast convergence rate would also be desirable, in this context. The Genetic Algorithm has provided good results so far, but there might be optimisation strategies with a better convergence rate and which find an optimum faster than the one applied within this research.

Finally, the bottom line is that this research has introduced a contribution to theory and practice, which provides many new research possibilities. Following discussions regarding the concept of FRA and MPPM as well as a worthy investigation, it can be concluded that the concept can be widened and adjusted to the needs and requirements of the specific application domain. Extending this concept by optimisation, generalisation, data mining and further research domains appears to be a promising opportunity and one with unlimited potential .

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A Simulation-based Decision Support System to improve Healthcare Facilities Performance – elaborated on an Irish Emergency Department

By

Dipl.-Ing. Michael Thorwarth

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Supervisor: Dr. Amr Arisha, *Ph.D., MSc.*

External supervisor: Professor Paul Harper, *Ph.D., MSc.*

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Appendix A

DVD-Contents

The DVD provided within this dissertation intents to provide everything necessary to reproduce the results obtained within this dissertation. It therefore contains:

- Source code for the data mining modules and functions;
- An extract of the raw data hospital data (without patient identification such as names, addresses etc. and just the first 750 female patients);
- Data mining results such as grouped data, and statistical results;
- Conceptual models: flow charts and IDEF0 model;
- Simulation model;
- Modules and libraries to rebuild the simulation model from scratch;
- Results of the simulation results;
- Function to process simulation results, like verification and validation.

The DVD is structured as following:

- **Data**

  Attendances-2007

  Attendances-2008

  GROUPED-DATA-2007

  GROUPED-DATA-2008

  PatientCalculation

  PatientCalculation-MultipleRuns

  SimulationResults

- **Documents**

  IDEF0-Model-ED-in-SVUH

- **Model**

  EmbTemplate 0.8.2

  EmbTemplate 1.0.4

  Interarrival Times 4 ExtendSim v2

  PatientCalculation-mwait2

  Resource Allocation-log

- **Modules and Libraries**

  - **ExtendSim**

    ED-FRA-Blocks
    Simple-FRA

  - **VisualBasic-Tools**

    CleanData - Verifies and checks data quality
    DeleteSheet - Module5
    PatientGr - Formating tools - Module3
    PatientGr - Necessary tools - Module2
    PatientGr - Needful tools - Module4
    PatientGrouping - Main - Modul1
    README to apply Data Mining functions
    Simple readme to apply the Makro

  - **Instructions for Tools**

Appendix B

Data Processing

B.1 Instruction to Apply Data Mining Functions

A ”read me” to apply the Data Mining functions:
Considerations:

- Due to memory limitations in Excel it is requested to run the Data Mining functions in a 64bit environment - e.g. either server or other desktop computers
- The Data Mining functions take some time to execute: if all 40,000 patients and all groups are to be analysed it may well take up to 12 hours until the results can be retrieved
- The first module contains global variables where configurations can be applied, such as
  - Directory location of the file,
  - Patient number (rows!) to be analysed,
  - Number of groups to be analysed
  - etc .·.
- The source code of the Data Mining functions are documented; I recommend reading it while adjustments to the global variables are made.
- HINT: In some cases it is not needed to calculate all the groups. If only statistical data for all patients would be sufficient then set the flag in the Procedure Analyse_Patient_Groups() from ”Analyse_Main_Table = True” to Analyse_Main_Table = False”

Procedure:

1. Open the patient data file and find the data in sheet1
2. Copy sheet1 into new .xlsm, save it - alternatively you have to make sure that the excel file has only sheet1.
3. Apply ”autofilter” to this excel sheet

4. From Developer tab, choose visual basic, and add the 5 modules in VeryFinal Data Mining functions Tools v1.2

5. In module1; there are 2 important things to set properly:

   - Public Const length As Long = 500 ’1406 ’41536 ’ 1000 ’35406’¡-edit here to the length of the table-1 or the length of the desired analysis
   - Public Const DirectoryInfo As String = `"C:\Users\Username\someFoleder\U` your folder!

6. Run the Data Mining functions, and enjoy ...

B.2 Data Conditioning / Data Mining

The following source code (listing B.1) displays the checking of the hospital data for its validity by making use of the redundancies within the delivered data. The here illustrated function scans the sums of the sub procedures and compares them with the total of the processes. In the case that the deviation is greater that 15 per cent, than the specific record is not marked as trustworthy and discarded for further evaluation. The remaining trustworthy data data is hence used to derive further filtering parameters for further processing.

```
Sub Analyse_patient_makro()

Application.ScreenUpdating = False   'saves a lot of time
Application.Calculation = xlManual   'saves a lot of time

Const Length As Long = 35406          'Length of list
Const tolerance As Double = 0.15  'Allowing rounding or typing errors

Dim i, j, k, l As Integer

Dim p_id(1 To Length) As Long
Dim p_sex(1 To Length) As String
Dim p_age(1 To Length) As Integer
Dim p_complaint(1 To Length) As Variant
Dim p_referral(1 To Length) As String
Dim p_specialty(1 To Length) As String

Dim p_regtime(1 To Length) As Date
Dim p_triagetime As Date
Dim p_treattime As Date
Dim p_admittime As Date
Dim p_dischargetime As Date
Dim rely_wait(1 To Length) As Boolean
Dim rely_total(1 To Length) As Boolean

```

```vb
Dim duration_wait4triage(1 To Length) As Variant
Dim duration_wait4treat(1 To Length) As Variant
Dim duration_waitingroom(1 To Length) As Variant
Dim duration_treatment1(1 To Length) As Variant
Dim duration_treatment2(1 To Length) As Variant
Dim duration_totaltime(1 To Length) As Variant
Dim duration_waitaftertreat(1 To Length) As Variant
Dim verify_wait(1 To Length) As Variant
Dim verify_total(1 To Length) As Variant
Dim p_triage_class(1 To Length) As Variant

Dim verify_w_test, verify_t_test, range_wait1, range_total1 As
    Boolean


Dim Header3 As Variant
Header2 = Array("ID", "Registration Time", "Age", "Sex", "Wait for
    Triage", _
                "Wait for Treatment", "Time in Waitingroom", "
                    Treatment Time1", _
                "Treatment Time2", "Wait for Admittance", "Total
                    Time", "", _
                "Verify Waiting Room", "Equal?", "Verify Total Time"
                    , "Equal?", "In Range", _
                "Triage Class", "Complaint", "Specialty", "Referal")
Header3 = Array("ID", "Registration Time", "Age", "Sex", "Complaint"
    , "Triage Class", _
                "Specialty", "Wait for Triage", "Wait for Treatment"
                    , "Time in Waitingroom", _
                "Treatment Time1", "Treatment Time2", "Wait for
                    Admittance", "Total Time", _
                "Referral", "", "Validate Wait", "Validate Total
                    Time")
'Header3 = Array("1_", "2__", "3__", "4__tegistration", "5____it for
    Triage", "6_me in Waitingroom", "7_eatment Time1", "8_eatment
    Time2", "9__t for Admittance", "10__l Time", "11", "12_Verify Wg
    Room", "13_al?", "14_ify Total Time", "15_al?")
'Header3= Array("1_", "2__", "3__", "4__t for Registration", "5_it
    for Triage", "6_me in Waitingroom", "7_eatment Time1", "8
    _eatment Time2")


' Prepare List for evaluation: List duration and indexrelyable data

Sheet2.Activate

' Set Header
For i = 1 To UBound(Header2) + 1
    Cells(1, i) = Header2(i - 1)
Next i

Call formatingrange 'make it nice


'Startloop----------Prepare List
    ---------------------------------------------------------------

For i = 1 To Length - 1
```

```
    verify_w_test = False
    verify_t_test = False
    ' ---- get values
    Sheet1.Activate

    p_id(i) = Cells(i + 1, 1)
    ' Name and Surname are not needed!!!
    p_age(i) = Cells(i + 1, 4)
    p_sex(i) = Cells(i + 1, 5)
    p_regtime(i) = Cells(i + 1, 6)
    p_triagetime = Cells(i + 1, 7)
    p_complaint(i) = Cells(i + 1, 10)
    p_triage_class(i) = Cells(i + 1, 11)
    p_treattime = Cells(i + 1, 12)
    p_specialty(i) = Cells(i + 1, 14)
    p_admittime = Cells(i + 1, 15)
    p_dischargetime = Cells(i + 1, 17)
    p_referral(i) = Cells(i + 1, 19)
    '----------------Calculate Duration with: get_time_difference
        ----------------
    duration_wait4triage(i) = get_time_difference(p_triagetime,
        p_regtime(i))
    duration_wait4treat(i) = get_time_difference(p_treattime,
        p_triagetime)
    duration_waitingroom(i) = get_time_difference(p_treattime,
        p_regtime(i))
    duration_treatment1(i) = get_time_difference(p_admittime,
        p_treattime)
    duration_treatment2(i) = get_time_difference(p_dischargetime,
        p_treattime)
    duration_totaltime(i) = get_time_difference(p_dischargetime,
        p_regtime(i))
    duration_waitaftertreat(i) = get_time_difference(p_dischargetime
        , p_admittime)

    Sheet2.Activate

    '--------------- index not valid data for waiting times
    If duration_wait4triage(i) = "Not valid" Or duration_wait4treat(
        i) = "Not valid" Then
        verify_wait(i) = "Not valid"
        verify_w_test = True
        Else:
        verify_wait(i) = duration_wait4triage(i) +
            duration_wait4treat(i)
    End If

    '--------------- index not valid data for total time
    If duration_wait4triage(i) = "Not valid" Or duration_wait4treat(
        i) = "Not valid" Or duration_treatment1(i) = "Not valid" Or
        duration_waitaftertreat(i) = "Not valid" Then
        verify_total(i) = "Not valid"
        verify_t_test = True
        Else:
        verify_total(i) = duration_wait4triage(i) +
            duration_wait4treat(i) + duration_treatment1(i) +
            duration_waitaftertreat(i)
    End If
```

```

    '---Fill the list:
    Cells(i + 1, 1) = p_id(i)
    Cells(i + 1, 2) = p_regtime(i)
    Cells(i + 1, 3) = p_age(i)
    Cells(i + 1, 4) = p_sex(i)
    Cells(i + 1, 5) = duration_wait4triage(i)
    Cells(i + 1, 6) = duration_wait4treat(i)
    Cells(i + 1, 7) = duration_waitingroom(i)
    Cells(i + 1, 8) = duration_treatment1(i)
    Cells(i + 1, 9) = duration_treatment2(i)
    Cells(i + 1, 10) = duration_waitaftertreat(i)
    Cells(i + 1, 11) = duration_totaltime(i)
    Cells(i + 1, 18) = p_triage_class(i)
    Cells(i + 1, 19) = p_complaint(i)
    Cells(i + 1, 20) = p_specialty(i)
    Cells(i + 1, 21) = p_referral(i)




    '---- Index datasets that are equal or within tolerance range


    '--------------- Validate Waiting times
    If verify_w_test = False Then  '- Test for valid results

        If CLng(verify_wait(i)) <> CLng(duration_waitingroom(i))
            Then
            Cells(i + 1, 13) = "No!"
            rely_wait(i) = False
        End If

        Cells(i + 1, 12) = verify_wait(i)

         '- check for verification of WAITING time is within error
            range +/-10%
        If ((CLng(verify_wait(i)) * (1 - tolerance) <= CLng(
            duration_waitingroom(i))) And (CLng(verify_wait(i)) * (1
             + tolerance) >= CLng(duration_waitingroom(i)))) Or ((
            CLng(duration_waitingroom(i)) * (1 - tolerance) <= CLng(
            verify_wait(i))) And (CLng(duration_waitingroom(i)) * (1
             + tolerance) >= CLng(verify_wait(i)))) Then
            range_wait1 = True
            Cells(i + 1, 12) = verify_wait(i)
            Cells(i + 1, 13) = "In Range"
            rely_wait(i) = True
        End If

        '- check for equality!
        If verify_wait(i) = duration_waitingroom(i) Then
            range_wait1 = True
            Cells(i + 1, 12) = verify_wait(i)
            Cells(i + 1, 13) = "OK"
            rely_wait(i) = True
        End If

    Else: Cells(i + 1, 12) = "Not valid"
```

```
    End If


    '---------------- Validate Total times
    If verify_t_test = False Then
        If CLng(verify_total(i)) <> CLng(duration_totaltime(i)) Then
            Cells(i + 1, 15) = "No!"
            rely_total(i) = False
        End If

        Cells(i + 1, 14) = verify_total(i)

          '- check for verification of TOTAL time is within error range +/-10%
        If ((CLng(verify_total(i)) * (1 - tolerance) <= CLng(duration_totaltime(i))) And (CLng(verify_total(i)) * (1 + tolerance) >= CLng(duration_totaltime(i)))) Or ((CLng(duration_totaltime(i)) * (1 - tolerance) <= CLng(verify_total(i))) And (CLng(duration_totaltime(i)) * (1 + tolerance) >= CLng(verify_total(i)))) Then
            range_total1 = True
            Cells(i + 1, 14) = verify_total(i)
            Cells(i + 1, 15) = "In Range"
            Cells(i + 1, 16) = 1
            rely_total(i) = True
        End If

        '- check for equality!
        If verify_total(i) = duration_totaltime(i) Then
            range_total1 = True
            Cells(i + 1, 14) = verify_total(i)
            Cells(i + 1, 15) = "OK"
            Cells(i + 1, 16) = 0
            rely_total(i) = True
        End If
    Else: Cells(i + 1, 14) = "Not valid"
    End If
Next i
'Endloop----------Prepare List----------------------------------------------------------------------



'---------------- DISPLAY RELYABLE DATA in sheet3!!!
Sheet3.Activate

' Set Header
For i = 1 To 18
    Cells(1, i) = Header3(i - 1)
Next i

'Call formatingrange 'make it nice


'Startloop----------DISPLAY GOOD----------------------------------------------------------------------
```

```
i = 2
For j = 1 To Length

    If (rely_wait(j) = True) And (rely_total(j) = True) Then
        Cells(i, 1) = p_id(j)

        Cells(i, 2) = p_regtime(j)

        Cells(i, 3) = p_age(j)
        Cells(i, 4) = p_sex(j)

        Cells(i, 5) = p_complaint(j)
        Cells(i, 6) = p_triage_class(j)
        Cells(i, 7) = p_specialty(j)


        Cells(i, 8) = duration_wait4triage(j)
        Cells(i, 9) = duration_wait4treat(j)
        Cells(i, 10) = duration_waitingroom(j)
        Cells(i, 11) = duration_treatment1(j)
        Cells(i, 12) = duration_treatment2(j)
        Cells(i, 13) = duration_waitaftertreat(j)
        Cells(i, 14) = duration_totaltime(j)

        Cells(i, 15) = p_referral(j)


        Cells(i, 17) = verify_wait(j)
        Cells(i, 18) = verify_total(j)

        i = i + 1
    End If
Next j

'Endloop----------DISPLAY GOOD------------------------------------------------------------------------






End Sub

Function get_time_difference(time1, time2 As Date)   'time1>time2 !!!!!

Dim Years1, Years2, Duration As Long
Dim Months1, Days1, Hours1, Minutes1, Months2, Days2, Hours2, Minutes2 As Integer
Dim dif_years, dif_dif_months, dif_days, dif_hours, dif_minutes As Integer

If (time1 <= 0) Or (time2 <= 0) Then
get_time_difference = "Not valid"
Else:

Years1 = Year(time1)
```

```
Years2 = Year(time2)
Months1 = Month(time1)
Months2 = Month(time2)
Days1 = Day(time1)
Days2 = Day(time2)
Hours1 = Hour(time1)
Hours2 = Hour(time2)
Minutes1 = Minute(time1)
Minutes2 = Minute(time2)


    dif_years = Years1 - Years2
    dif_months = Months1 - Months2
    dif_days = Days1 - Days2
    dif_hours = Hours1 - Hours2
    dif_minutes = Minutes1 - Minutes2

    Duration = dif_minutes + dif_hours * 60 + dif_days * 60 * 24 +
        dif_months * 60 * 24 * 30 + dif_years * 60 * 24 * 30 * 12
    If Duration < 0 Then
        get_time_differenc = "Not valid"
        Else:
        get_time_difference = Duration
    End If
End If

End Function
```

Listing B.1: Function to retrieve trustworthy data from the hospital records

B.3 Patient Complaint Types

Table B.1: Patient with the different complaints coming to the ED in SVUH. The lines indicate where the summed percentage of the amount is exceeding 5per cent and 15 per cent.

#	Row Labels	Count of Complaint	
1	Unwell Adult	3134	100%
2	Abdominal Pain in Adults	2499	79%
3	Shortness of breath in adults	1656	62%
4	Limb Problems	1639	51%
5	Chest Pain	1221	39%
6	Collapsed Adult	624	31%
7	Urinary Problems	445	27%
8	Falls	424	24%
9	Diarrhoea and vomiting	317	21%
10	Abscesses and local infections	301	19%
11	GI Bleeding	274	17%
12	Back Pain	271	15%
13	Headache	224	13%
14	Sore Throat	223	12%
15	Wounds	221	10%
16	Fits	137	9%
17	Major Trauma	115	8%
18	Mental Illness	105	7%
19	Head Injury	100	6%
20	Overdose and Poisoning	95	6%
21	Facial problems	90	5%
22	Diabetes	85	4%
23	Diarrhoea	77	4%
24	Testicular Pain	75	3%
25	Palpitations	68	3%
26	Foreign Body	38	2%
27	Eye Problems	35	2%
28	Asthma	34	2%
29	Behaving Strangely	33	1%
30	Rashes	30	1%
31	Neck Pain	27	1%
32	PV Bleeding	24	1%
33	Self-harm	16	1%
34	Burns and Scalds	16	1%
35	Ear Problems	13	1%
36	Torso injury	12	0%
37	Allergy	12	0%
38	Assault	11	0%
39	Bites & Stings	6	0%
40	Apparently drunk	6	0%
41	Pregnancy	5	0%
42	Abdominal Pain in Children	4	0%
43	Irritable Child	3	0%
44	Shortness of breath in children	2	0%
45	Haematological Disease	1	
	(blank)		
	Grand Total	**14748**	

Appendix C

Alternatives to Simulation Modelling Procedure

The latest recommended simulation modelling procedure (see Figure C.1) is provided by Banks et al. (2005) and suggests that each project should start with a clear problem definition (1) and statement of objectives (2). At this point, the modeller should be able to state whether DES offers the desired solution to the problem. An overall project plan helps to estimate the effort required. During the data collection process (3) and analysis phase, a conceptual model (4) is designed. This conceptual model is a raw model which reflects the process flow at a high grade of abstraction (Robinson 2007*a*, Robinson 2007*b*). The analysed data and the conceptual model build the basis for the simulation model which will be implemented (5). The retrieved data is combined with the conceptual model in a translated simulation model. To assure that the simulation model replicates the real system Kleijnen (1995) offers detailed discussion and analysis strategies for verification and validation. Verification (6) assures that the processes of the simulation model are behaving logically as expected, while validation (7) tests that the results of the model fit the actual system.

Experimental design (8) tests the simulation model for improvements by applying scenarios, which may be tested systematically during the modelling phase. Subsequent to the experimental design production runs and analysis (9) establishes performance measures for the actual designed system. More runs (10) may be essen-

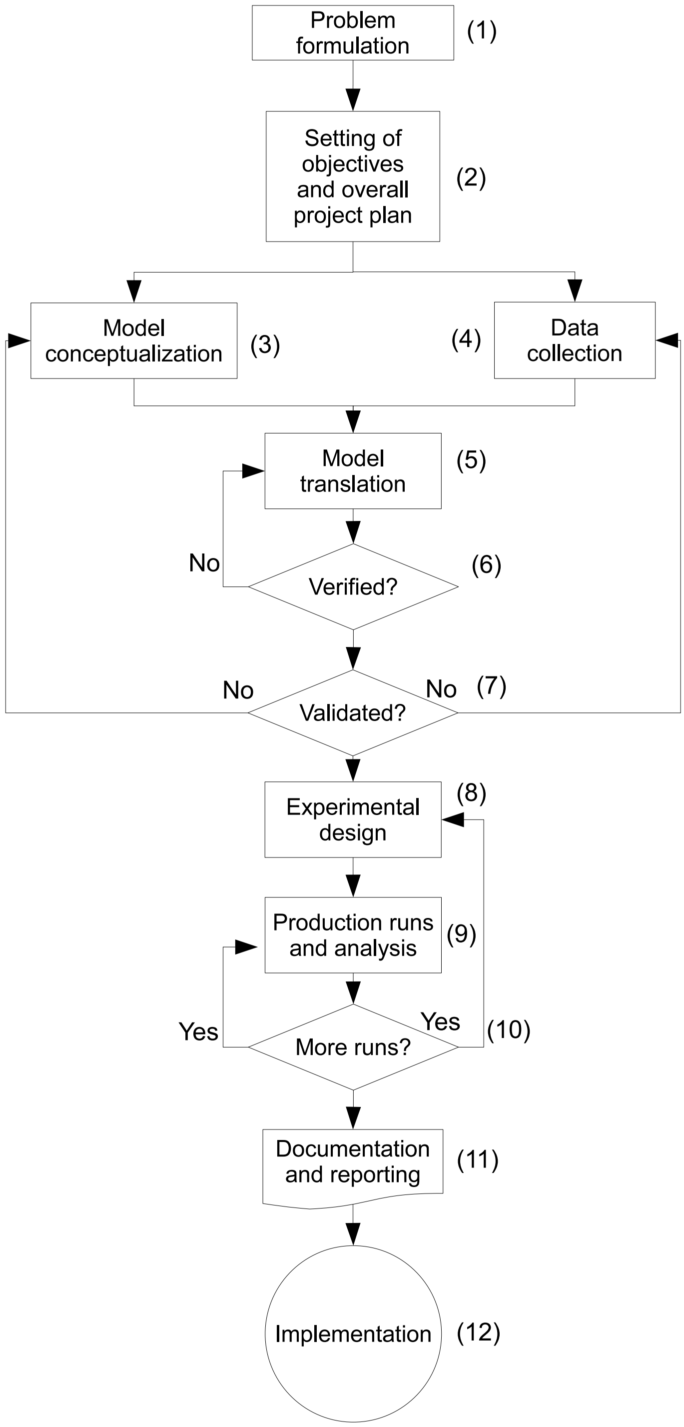


Figure C.1: Latest general procedure for simulation projects. *Source: Banks et al. (2005).*

tial for sensitivity analysis. In many theoretical applications the documentation and reporting (11) defines the final phase, while implementation (12) of the results of the model concludes the whole procedure. Clearly, as mentioned in chapter 3.3, the post project evaluation is not mentioned within this approach, that Banks et al. (2005) mentioned. It can be argued that post project evaluation is not concerned with the actual core processes of the modelling procedure, and that the activities concerning the modeller are completed with the implementation. However, evaluation, in the type of a comparison on how well the results were predicted, can provide invaluable information for the quality of the overall project.

C.1 BPMN 2.0 Guide for Template Design

In order to illustrate the FRA on a broader basis, BPMN 2.0 is facilitated. This conceptual modelling technique is a widespread adopted graphical notation which has been set as a standard by the Business Process Management Initiative (BPMI) (Business Process Management Initiative 2010). One of the strengths of this activity diagram in comparison to flow charts is the adoption of Unified Modelling Language in a profound and structured method. BPMN allows an interconnected mapping of activities of several processes with information flow, subdivision among several user groups, and with a definition of a notation that includes hierarchies of services / processes. The mapping is illustrated in Business Process Diagrams (BPD), which mechanisms are illustrated in the following images.

The processes are triggered with starting events and end with an ending event. Intermediate events are also possible that either cause an interruption or restarts a process, based on an external event or a timed event. Events also trigger an information flow that initiates messages among processes. Figure C.2 illustrates examples on event classification.

These events manage the communication and sequentialisation of the task that

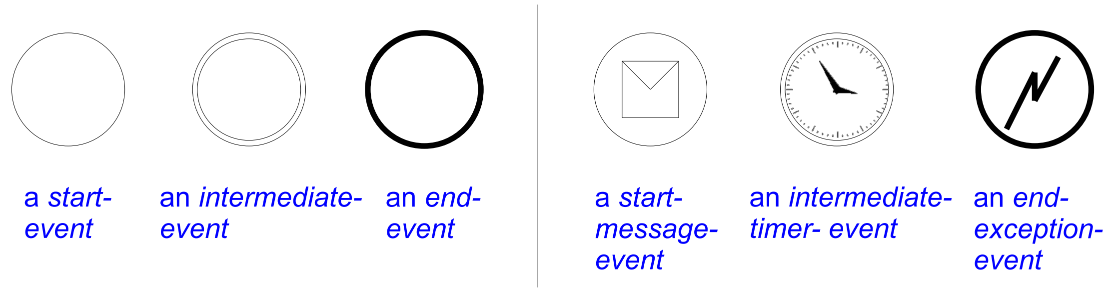


Figure C.2: Events illustrated in BPMN 2.0. *Source: BPM Offensive Berlin (2010).*

can be grouped in a hierarchical way, allowing inheriting sub processes. An example for a task including sub task is provided in Figure C.3.

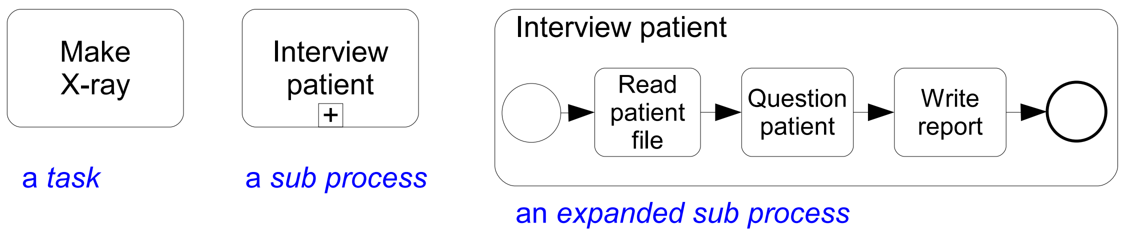


Figure C.3: Hierarchy illustrated in BPMN 2.0. *Source: BPM Offensive Berlin (2010).*

There are three types of flow associations among processes within BPMN: sequence flow, message flow, and association. The sequential flow is an arrow with a straight line, the message flow is an arrow with a dashed line, and the association is a dashed line (see Figure C.4.

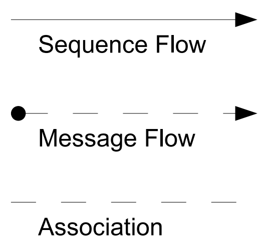


Figure C.4: Sequential flow illustrated in BPMN 2.0. *Source: BPM Offensive Berlin (2010).*

The flow of the processes can be diverted on certain conditions. To facilitate this conditional decision points divert the processes – on the other hand processes can be merged unconditionally. The notation for the decision points is provided in Figure C.5.

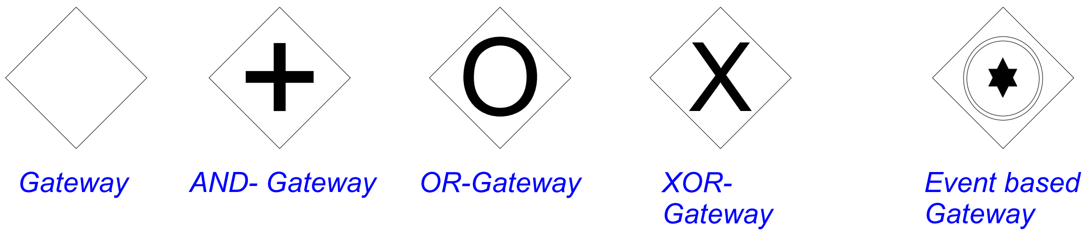


Figure C.5: Decision points illustrated in BPMN 2.0. *Source: BPM Offensive Berlin (2010).*

Including annotations is also a valid way to include documentation or reports that have to be triggered with in a business process. An example for annotation is displayed in Figure C.6 where also the application of grouping is displayed.

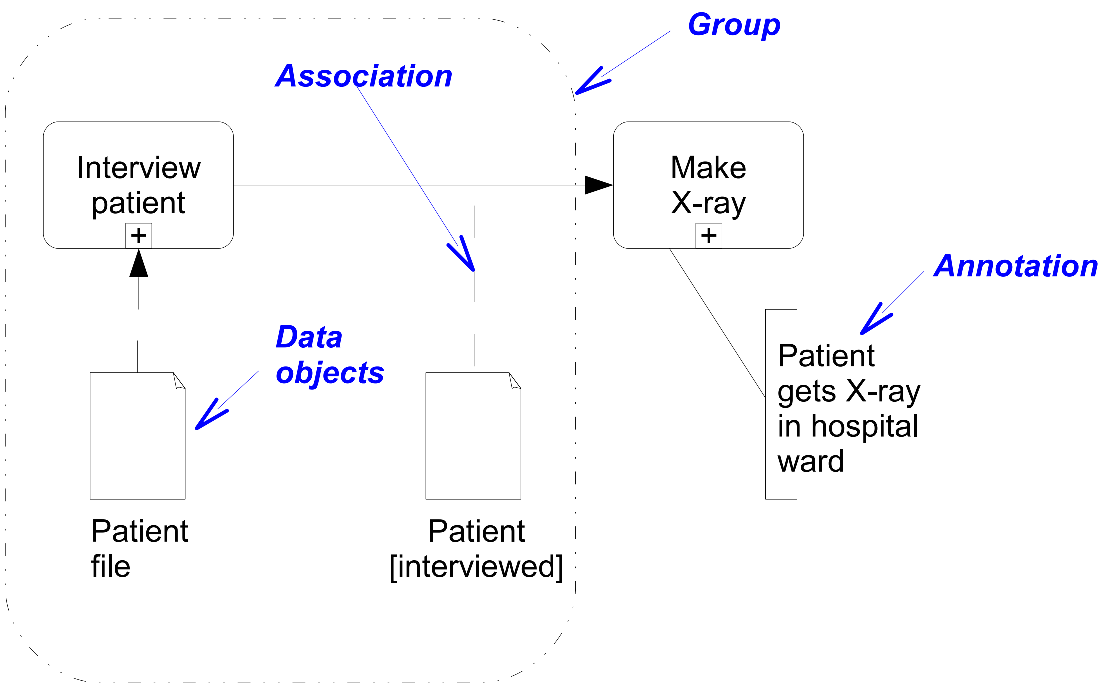


Figure C.6: Groups and annotation illustrated in BPMN 2.0. *Source: BPM Offensive Berlin (2010).*

Within the Figure C.6 it can be seen that groups can also be assigned which are encapsulated from the outside. This grouping is a transparent hierarchy.

An example of an illustrated business process is provided in Figure C.7. This business case is triggered by a message at 6 o'clock which starts the process that checks the status of the working group. If the working group is still active it sends the current issue list. In case the working group is not active, an error event will be triggered.

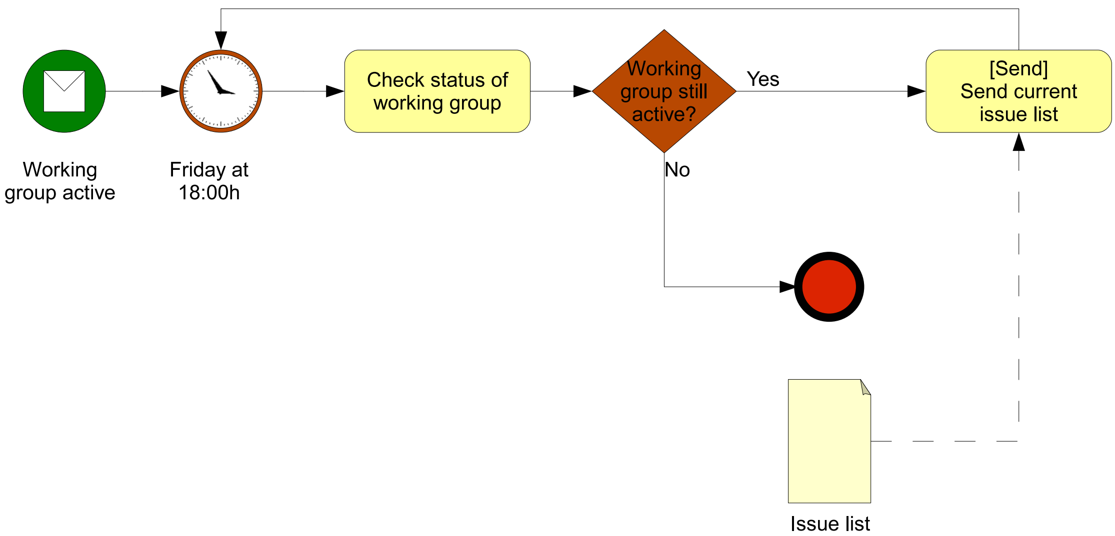


Figure C.7: A simple business case example illustrated in BPMN 2.0. *Source: BPM Offensive Berlin (2010).*

BPMN is chosen because it can represent various flowcharts with a high degree of expressiveness, simplicity, and scalability, which will be essential in the explanation stage of FRA. It is therefore very flexible and can be applied in many domains, which is one of the reasons why it has widely distributed and also accepted in health care(Rojo et al. 2008). BPDs are recently investigated and studied as a proposed conceptual modelling techniques for health care simulation, which resolved as its application is highly recommendable (Onggo 2009). As conceptual modelling is one inherited part of the simulation modelling procedure, it is highly recommendable to deliver the concept of FRA with a highly accepted activity diagram such as BPMN. Its flexibility also allows describing the control mechanism within the modules as well as the necessary logic outside of the described modules to a broad audience.

Appendix D

Optimisation

Due to the dynamics of the FRA simulation model, a local optimum could be identified which is different to the global optimum. Table D.2 illustrated the simulated outcome of the setting identified in table D.1 in comparison to the original hospital records.

This result is obtained and identified by having run the simulation model multiple times and these results appeared in five observations. It is therefore a valid partial solution, yet not a global optimum.

Table D.1: Optimum parameter setting of the identified local Minimum.

Staff	**Number**
Cleaners	7
Porters	4
Nurses	20
Doctors	22
Senior Doctors	10
Consultants	6

Table D.2: Local Optimum of optimisation run, which can be tested and validated.

Data origin	Process Stage / Statistical characteristics	Waiting Room (first wait)	Waiting Room (second wait)	Treatment Unit 3	Treatment Unit 2	Treatment Unit 1	Length of stay
Hosiptal records	**Target Value for 2008**	**10,61**	**261,05**	**152,94**	**159,57**	**222,42**	**524,03**
Optimization results	**Total Average**	**10,17**	**18,47**	**119,10**	**124,44**	**39,88**	**396,87**
	Standard Deviation	0,69	18,09	0,65	0,31	0,32	38,69
	Confidence Area 99%	0,69	18,13	0,65	0,31	0,32	38,78
	Confidence Interval 99% [Lower bound]	9,48	0,34	118,44	124,13	39,56	358,09
	Confidence Interval 99% [Upper bound]	10,86	36,60	119,75	124,74	40,20	435,65
Comparison of results	**Difference to Target Value**	**95,8%**	**7,1%**	**77,9%**	**78,0%**	**17,9%**	**75,7%**
	Error Rate based on 99% Confidence Interval	6,8%	98,2%	0,5%	0,2%	0,8%	9,8%

Appendix E

Modelling

E.1 Description of the Applied IDEF0 - Model Technique

IDEF0-Model As both an alternative and as a supplement, the IDEF0 scheme is chosen and facilitates the structure of hierarchical modelling. A complete manual for the IDEF0 standard can be obtained from the secretary of commerce who issues the Federal Information Processing Standards Publications (FIPS PUBS) (National Institute of Standards and Technology 2011, de Bruin et al. 2007). The processes are represented by boxes which have different types of arrows attached to them (see Figure E.1). The attachment is located on different areas of the boxes, which determines the different functions of the arrows. The arrow pointing in the box on the left side declares the inputs of the particular process. The arrow pointing to the top of the box represents the controls and the arrow pointing out on the right indicates the output of the process. On the bottom side there are two additional arrows attached, the first inward arrow represents the mechanisms, and the other outgoing arrow delivers calls of the process.

In practice, the patient would be the input and the output of a treatment process, in order to illustrate the flow of the processes. The control delivers the information that is needed to treat the patient successfully. The mechanisms are represented here by the need of certain resources. The resources are represented by coloured boxes on the left side, which function as a resource pool. Calls are an outgoing information

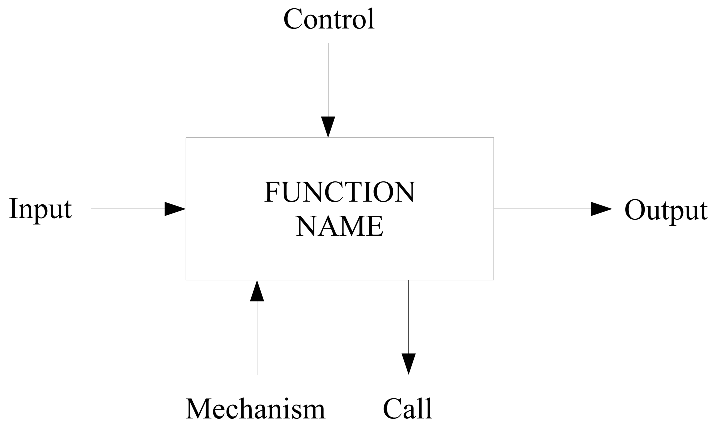


Figure E.1: Principle Mechanism for IDEF0 models illustrated on a basic module.*Source: National Institute of Standards and Technology (2010)*

arrow, that delivers information to subsequent processes. With these five functions attached to the process, a wide variety of processes can be mapped. Another strong component of IDEF0 is the fact that it allows hierarchical modelling. In order to make use of the hierarchies the processes are labelled in a certain manner: Each process is labelled as node – here within this example (Figure E.2) the fourth level of the chest pain treatment is displayed. Therefore the node is labelled as the A4 and all sub processes (or sub nodes) are hence labelled with A4x which indicates the process order. Thus, for example, the third step, which is the Diagnostic Imaging would be labelled as A43. With this scheme, the hierarchy level and the process step can easily be retraced. The IDEF0 allows mapping and tracing the process flow down to the highest detail level and also helps to indicate which resources are required for which process.

To coordinate the process mapping it is recommended to make use of the standardised frames, which allow the reader to see in which hierarchy level the displayed node is placed, and also to see the actual label of the current node. Additional information of the author, creation date and also revision date can also be retrieved. The revision date, allows for the documentation of when the process received approval by a knowledgeable staff member and the name of this staff member. The context window in the upper right provides an overview of the upper hierarchy node. The

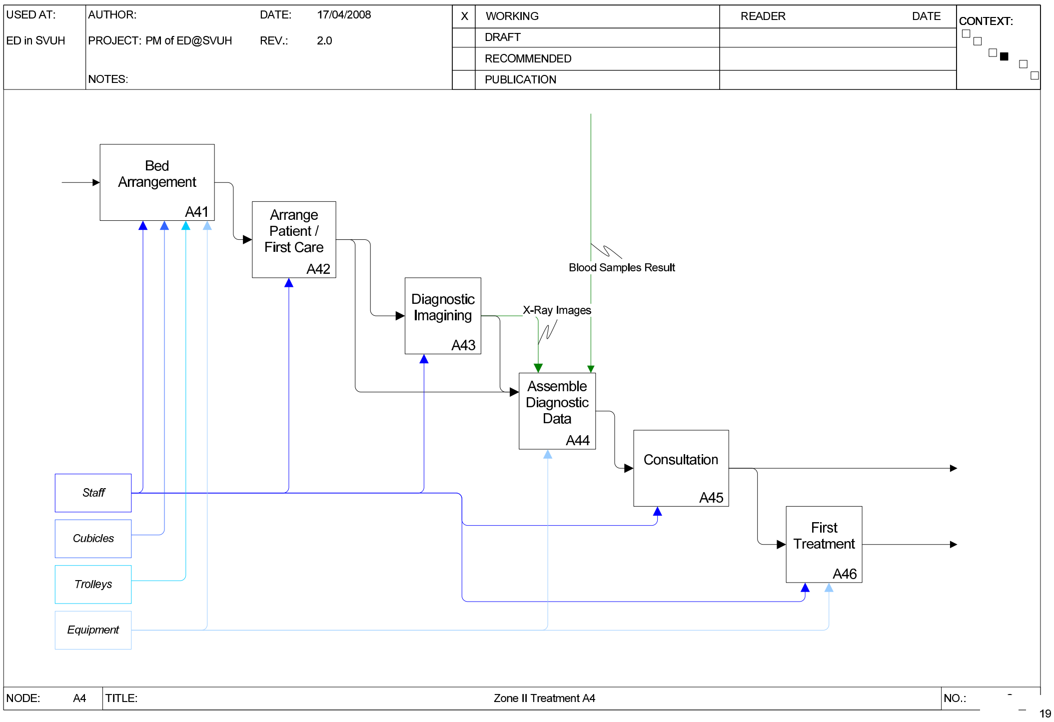


Figure E.2: 4th level IDEF0-hierarchy slide to represent chest pain process in treatment.

whole IDEF0 document is amended on the appendix within the DVD. In order to increase readability, the left side provides a description in written words of the process and also a small picture of the upper hierarchy level. On the right side of the opened booklet the actual IDEF0 node documentation is provided. For the very first hierarchy level, where no upper node is available, a summary of the overall process is given plus the process flow chart, which has been used previously to generate the over merged process flow chart.

The hierarchical structure displays the processes in a very ordered way. For example, the first hierarchy level displays all process stages that are similar to the process flow charts obtained from the interviews. The second hierarchy level shows the sub processes within the first level process. This means that for the triage of a psychiatric patient there are the following sub processes involved: first assessment, process details, get blood samples, arrange x-ray, and store patient record. Getting blood samples and arranging x-rays are dependent on the provided information provided by the patient in conjunction with the patient record and may either or be

Figure E.3: IDEF0 Model Booklet for ED in SVUH

executed or even skipped (compare Figure 3.2). The following four resource types are distributed to the processes according to the arrows: staff, cubicles, trolleys and equipment (assorted).

E.2 IDEF0 - Model to Describe ED in SVUH

The following IDEF0 booklet is used for validation of the model assumptions of the ED in SVUH. In the appendix there are two sheets placed on one page, which are originally printed on one page. Both sides of the page are printed so that the reader could see the overview and the explanation on the top, and the detailed model on the bottom.

These pages contain redundant explanations of the 'turn over' page for a better readability. Without the redundant information the reader would be almost lost within the *"jungle"* of process information. An additional drawback of IDEF0 is that the process maps are not self explaining – the reader needs at least an introduction, on how the graphs are read. Even though the display in IDEF0 is not the best option as a conceptual model on its own, it is a valuable supplement to other graphs, such as the process flow chart, used here in this dissertation.

This effect is similar to the appendix here. Pages that are technically left blank, in order to follow this arrangement, are marked as such.

Process Map
of Emergency Department
# of St. Vincent University Hospital

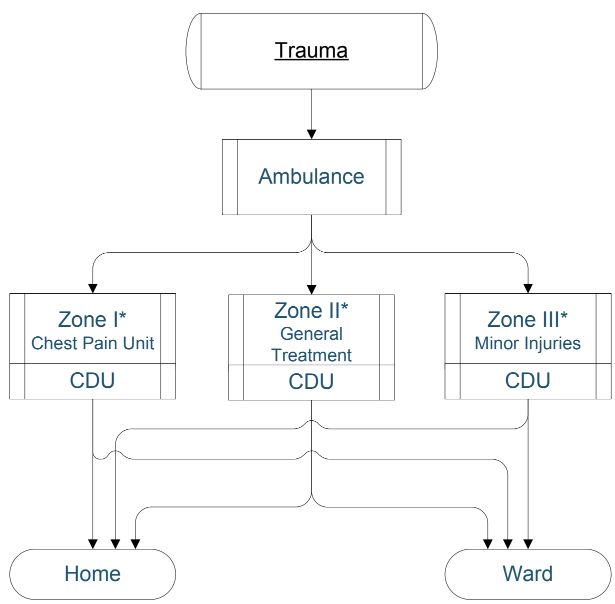
General Processes in the Emergency Department:

1 Trauma patients 1
2 Chest pain 19
3 Abdominal pain 35
4 Unconscious patients 51
5 Patients feeling dizzy 63
6 Minor injuries 77
7 Patients with stroke 95
8 Generally unwell patients 109
9 Patients with a respiratory illness 123
10 Patients with burns 139
11 Paediatrics 153
12 Gynaecological complaints 163
13 Psychological complaints 175
14 Sepsis / very sick patients 193

USED AT:	AUTHOR:	DATE: 17/04/2008	X	WORKING	READER	DATE	CONTEXT:
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Patients with a trauma

Patients with trauma skip triage, which is already been done in the ambulance. Depending on their case they are placed in one of the three Zones: Zone III is the most common path, but depending on capacity the patients may be placed in Zone II or Zone I (rarely). Zone I is reserved for patients with chest pain. Within the Zones the patients are being further assessed and treated. A diagnosis is done based on all gathered data combined with the latest blood samples and X-Ray Images (or CT).
The Clinical Decision Unit (CDU) monitors the patient for a proper time period and decide on keeping or releasing the patient.



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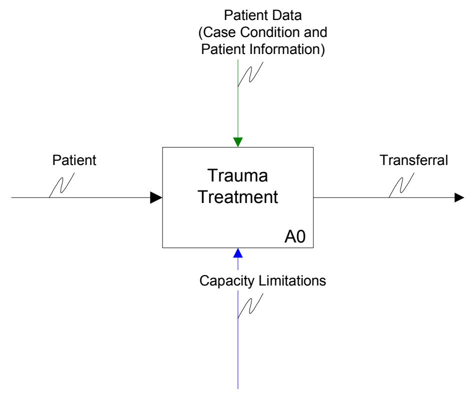

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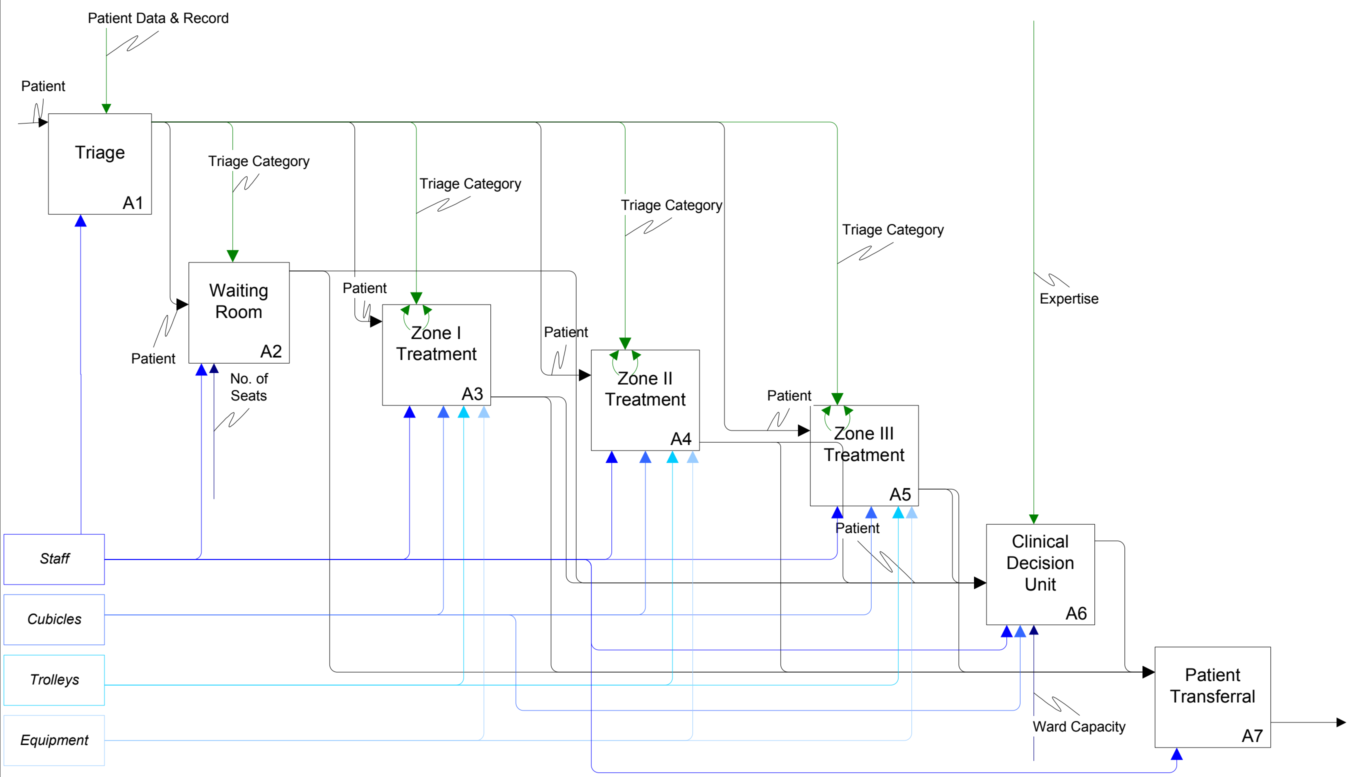

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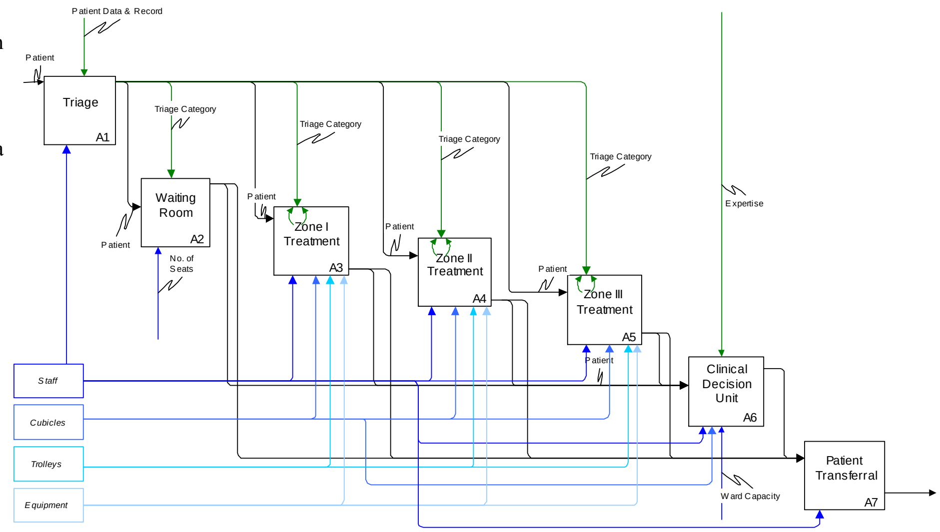
X	WORKING	READER	DATE
	DRAFT		
	RECOMMENDED		
	PUBLICATION		

CONTEXT:

Triage

In cases of trauma the patient is triaged within the ambulance. The patient is assessed based on the accident and a patient record is made. The details obtained from the patient are then handed to the administrational staff. Blood samples are taken as soon as the patient is in a safe environment. The administrational staff is then arranging an appointment for X-Ray. All the findings and diagnostic results are stored in a patient record.



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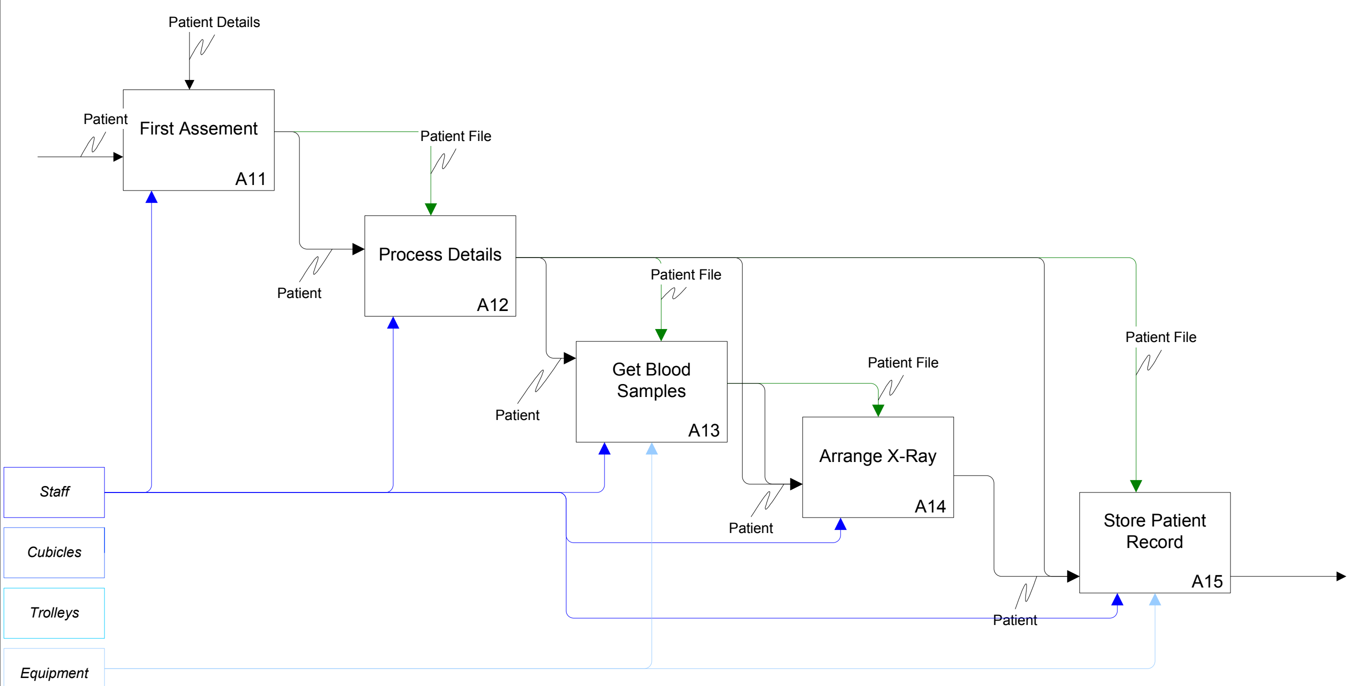
CONTEXT:



NODE: A1 | TITLE: Triage A1 | NO.: 1

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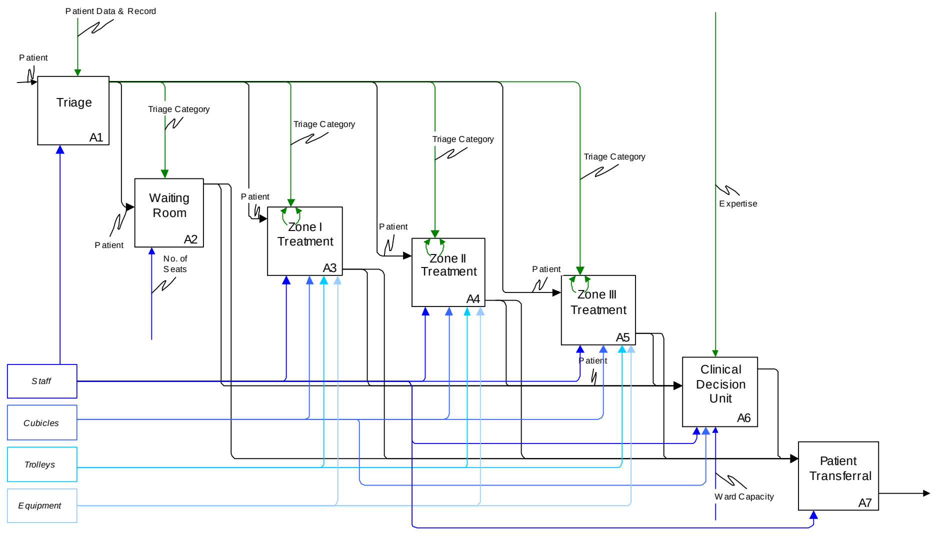
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Waiting Room

In low severe cases and full capacity of the ED the patient will be sent back to the waiting room. Patient waits for X-Ray. After X-Ray the patients have to wait in a preset location to discuss their cases.



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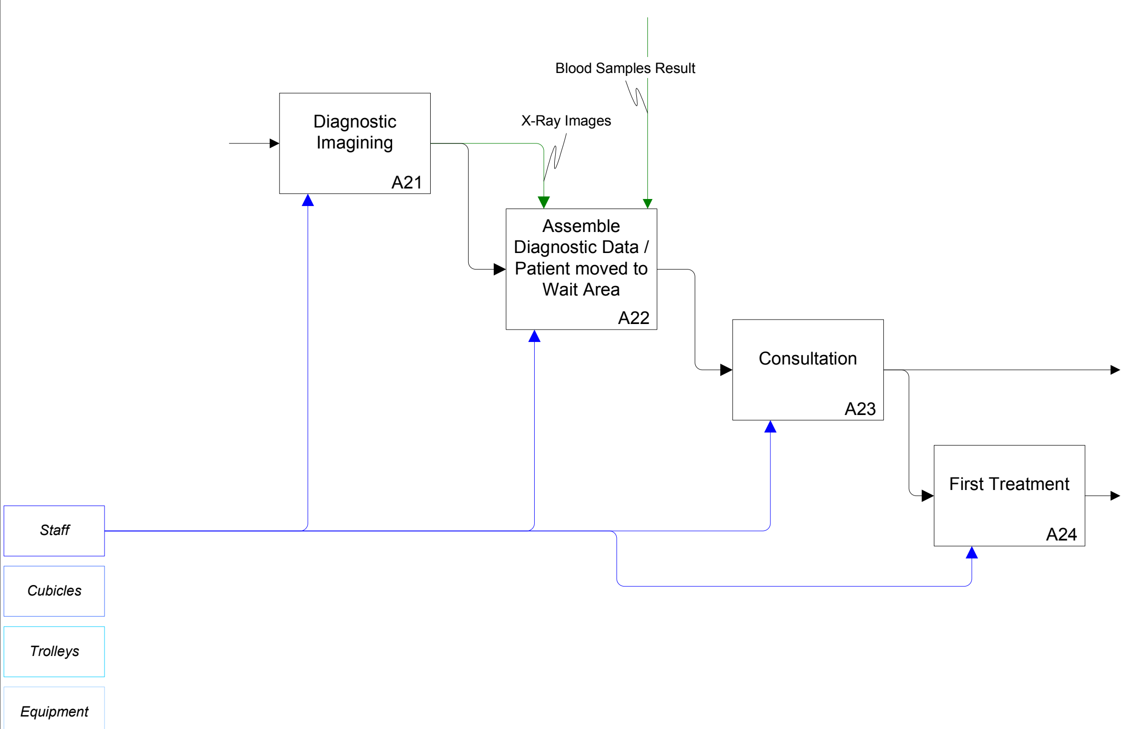

NODE: A2	TITLE: Wait Room A2	NO.: 1

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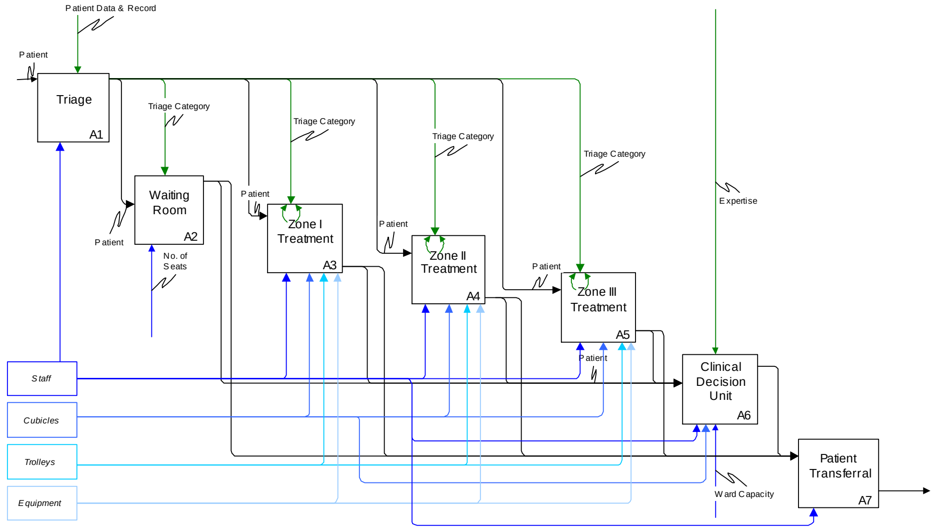
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone I

The basic procedures are similar to Zone II. Zone I is reserved for Chest Pain patients, but in cases of overcrowding of Zone II and Zone I might be used for trauma patients.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases. As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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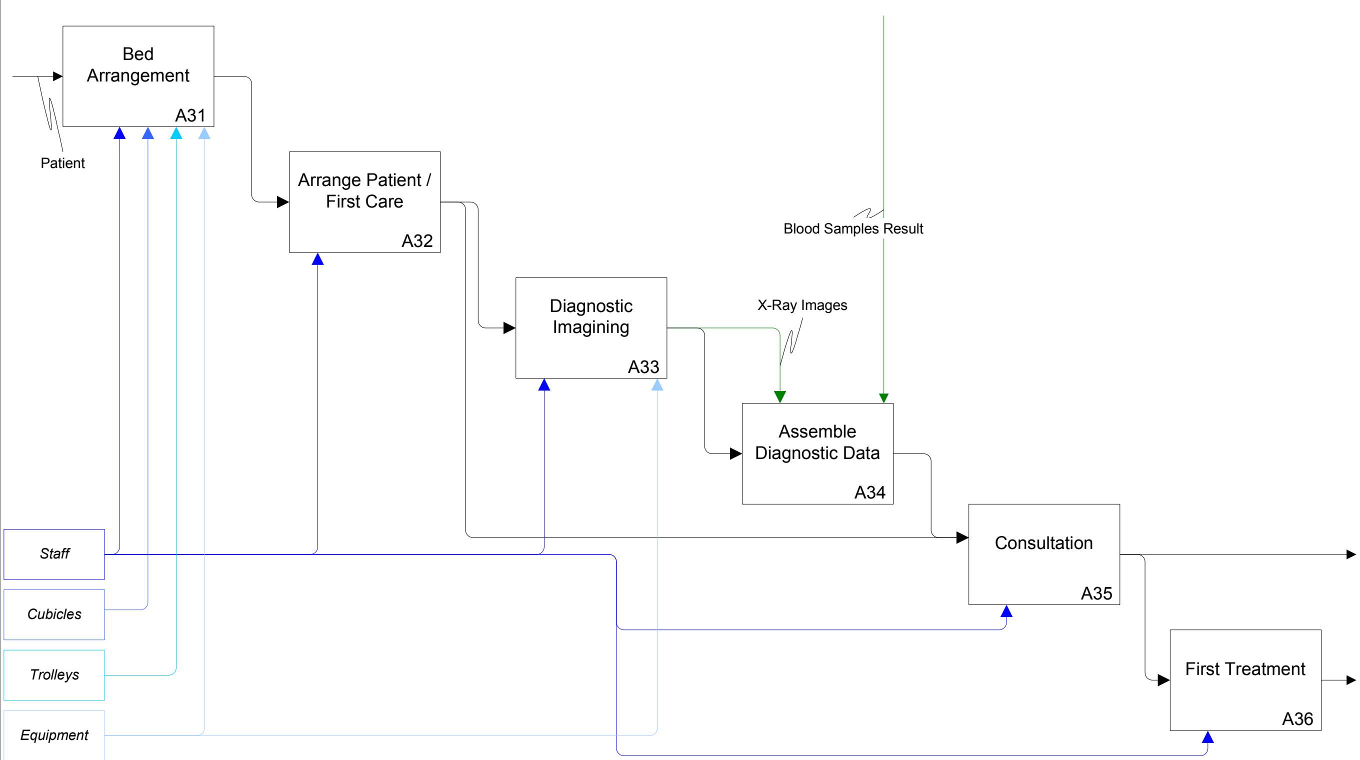
	NOTES:			PUBLICATION			

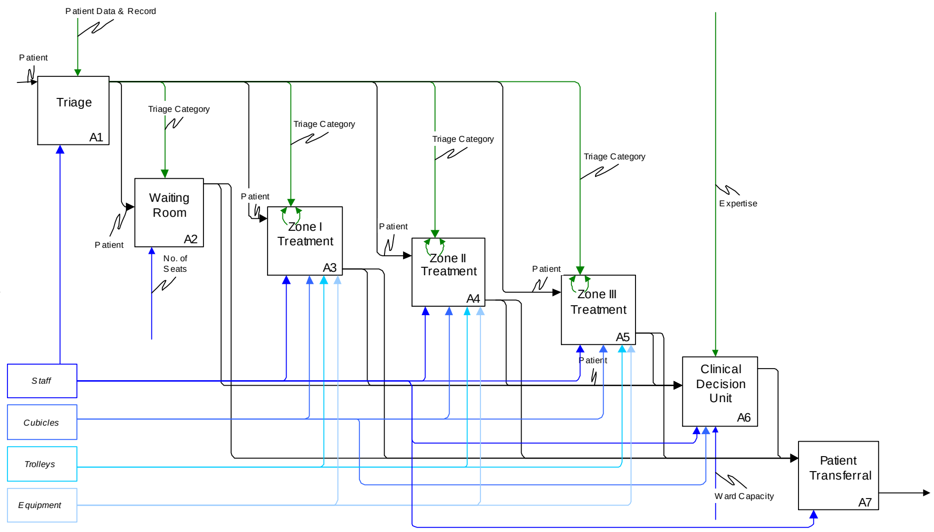


NODE: A3	TITLE: Zone I Treatment A3	NO.: 1

USED AT:	AUTHOR:	DATE: 17/04/2008	X	WORKING	READER	DATE	CONTEXT:
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone II

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases. As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



NODE: A0	TITLE: Trauma A0	NO.: 1

USED AT:	AUTHOR:	DATE: 17/04/2008	X	WORKING	READER	DATE	CONTEXT:
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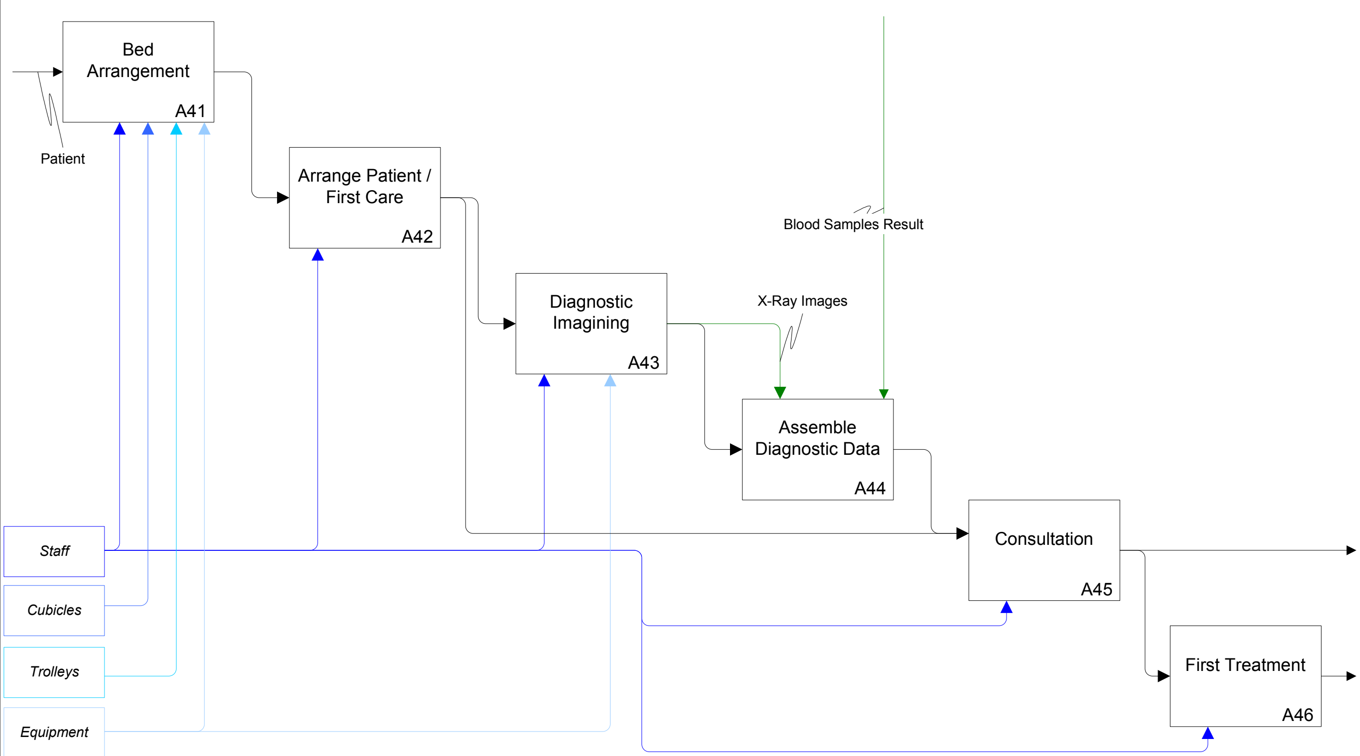

NODE: A4	TITLE: Zone II Treatment A4	NO.: 1

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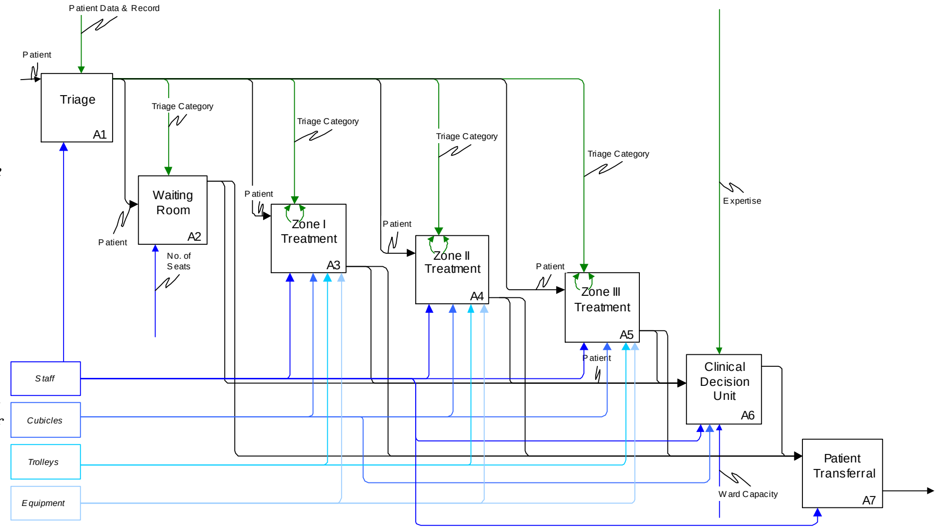
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone III

Zone III is mainly for patients of the 'Minor Injuries'. Trauma patients are also treated in here if they are in an stable condition. The treatment procedures are similar to Zone I and II.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases. As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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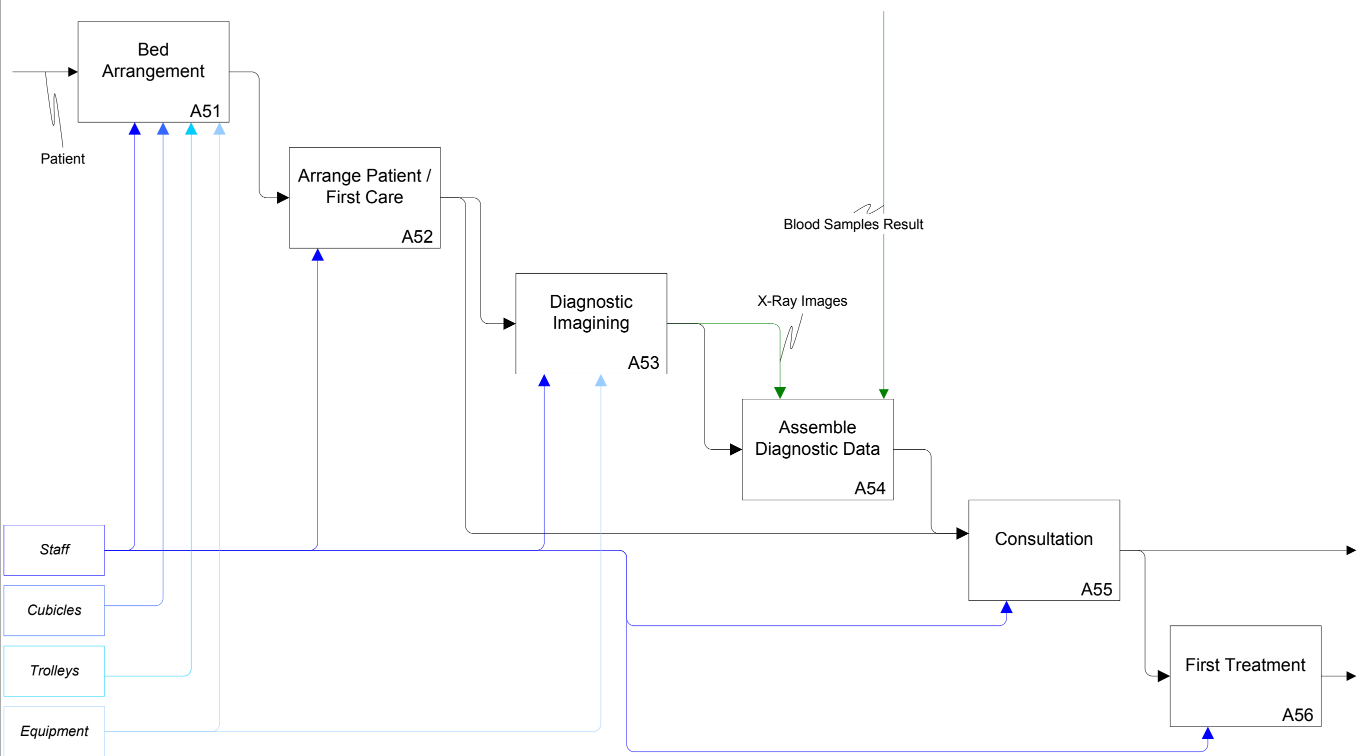

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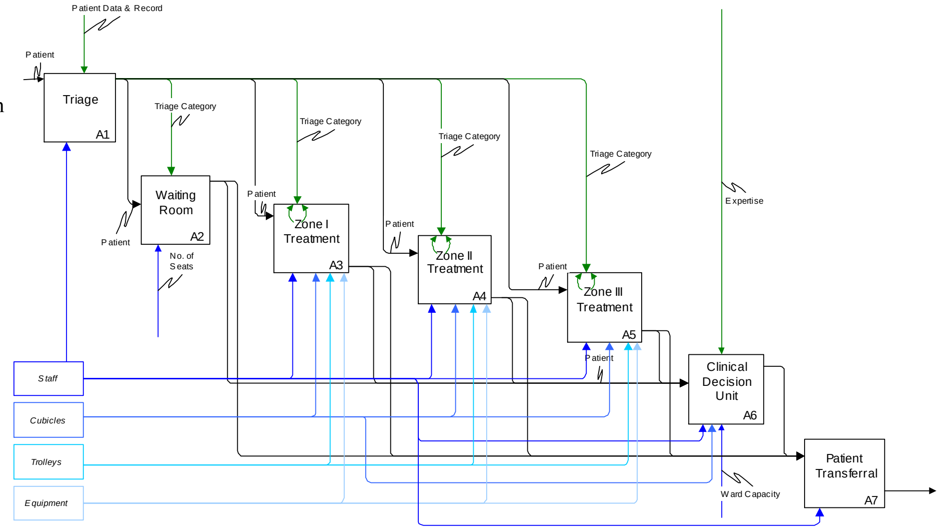
				RECOMMENDED			
	NOTES:			PUBLICATION			

Clinical Decision Unit

The Clinical Decision Unit (CDU) where the final decision is made whether to hospitalize the patients or sent them home. The decision is subject to patient condition and results from a considerable monitoring for the case status.



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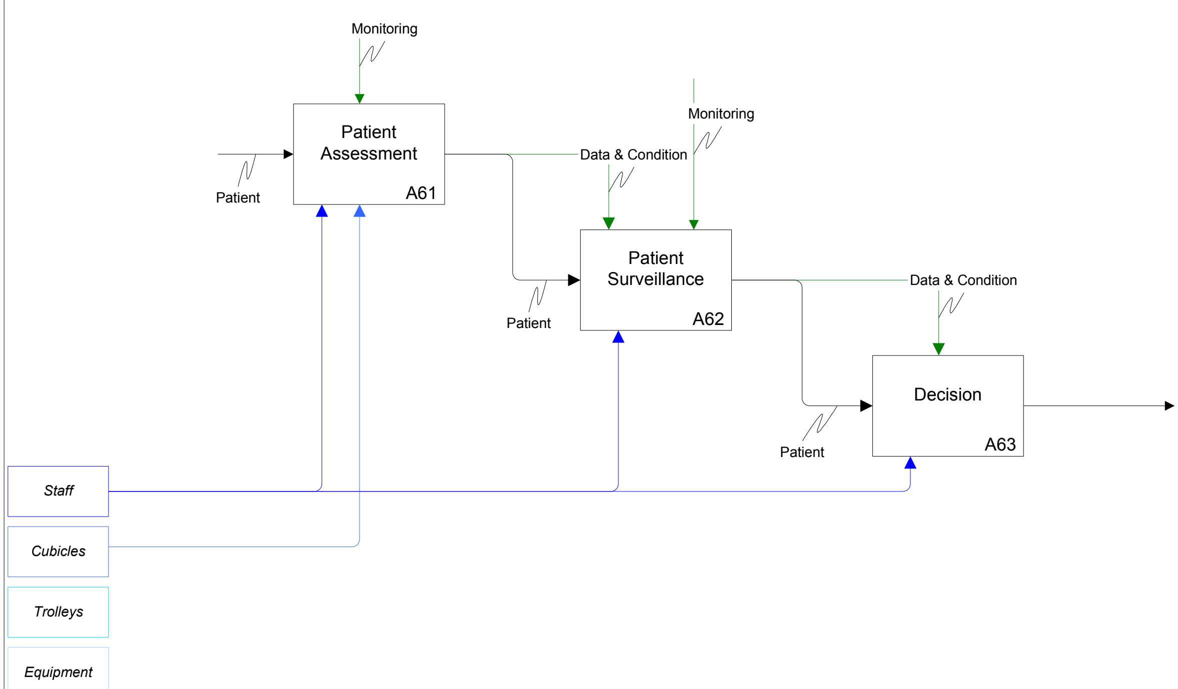

NODE: A6	TITLE: Clinical Decision Unit A6	NO.: 1

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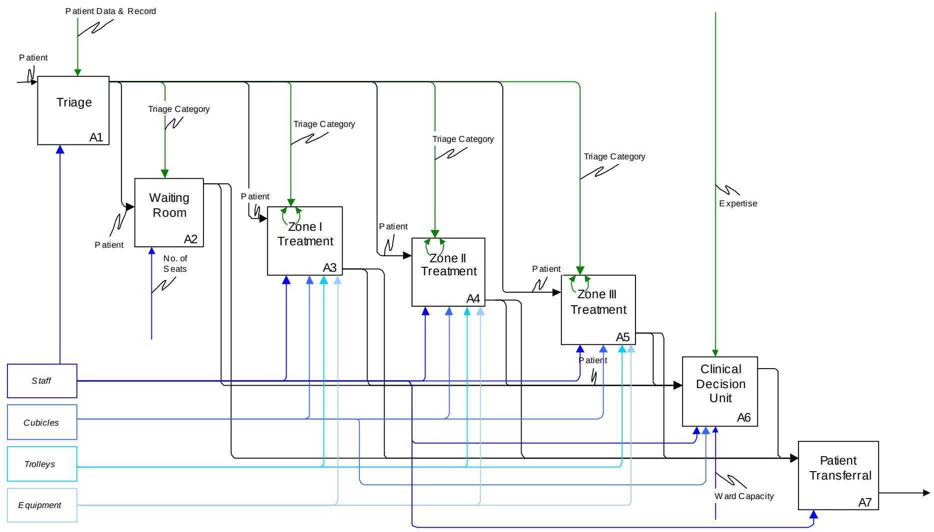
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Patient Transferal

Before any patient is ready to leave the ED, the patient record will be updated. The patient will either wait in his cubicle or moved to the corridor to free up a cubicle. Nurses usually look after the patient who are supposed to leave the hospital until they will be collected or driven home.



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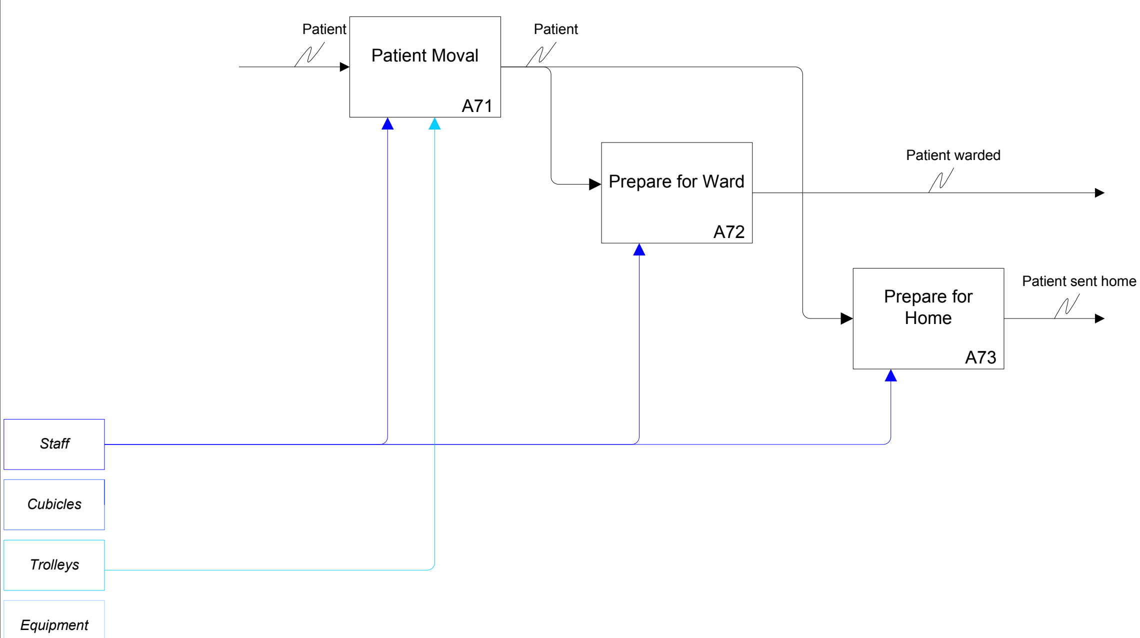

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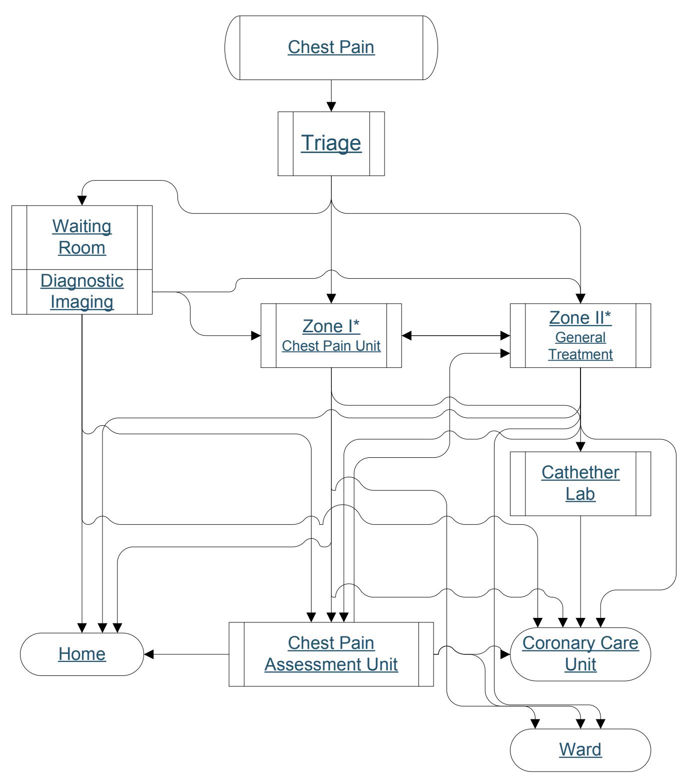
ED in SVUH	PROJECT: PM of ED@SVUH	REV.:	2.0		DRAFT			☐
					RECOMMENDED			
	NOTES:				PUBLICATION			

Patients with chest pain

Patients with chest pain are receiving a high triage category level. After triage they are sent to the chest pain unit which is located in Zone I. In case of low capacity, cubicles of Zone II may be used. Swapping patients is an option for emergency cases. Patients with minor severity are able to wait in the waiting room for assessment and treatment. Patients located in the chest pain unit (Zone I) are moved to the catheter lab, or the coronary care unit (CCU), or the chest pain assessment unit or home. All routes are depending on their severity level and case. From the chest pain assessment unit the patients are either transferred home, to the CCU, to the ward or wait in Zone II for further treatment. From Zone II they either get home, to the CCU, or are waiting to be warded.



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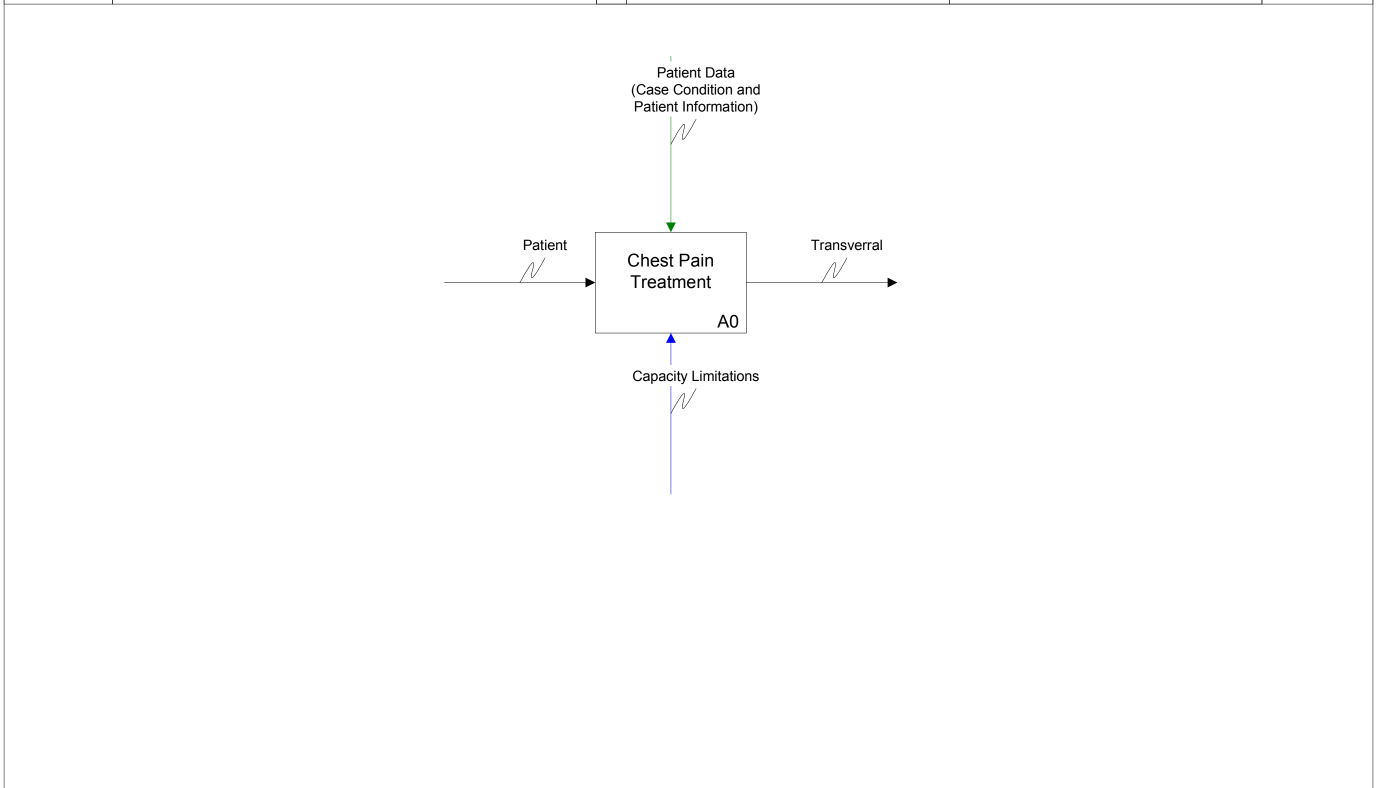

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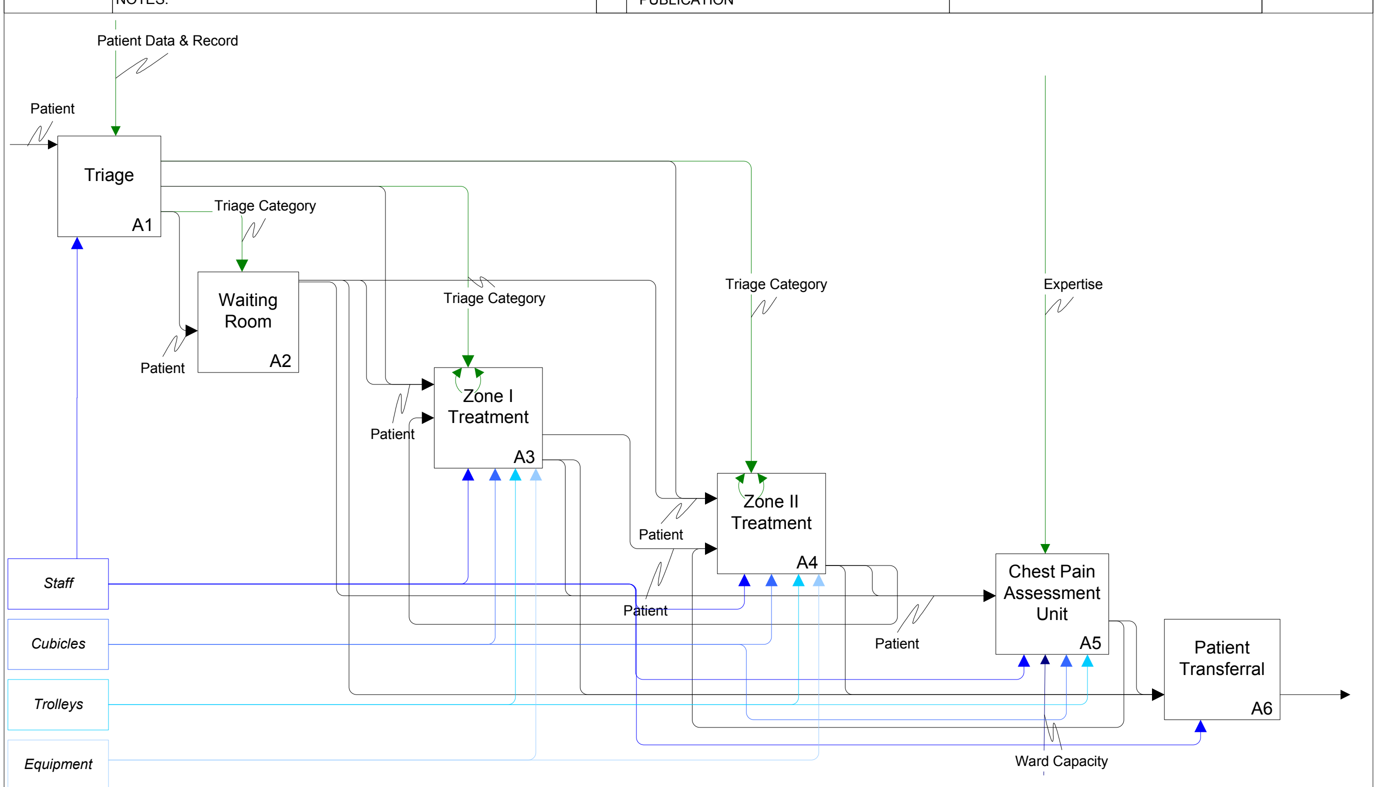

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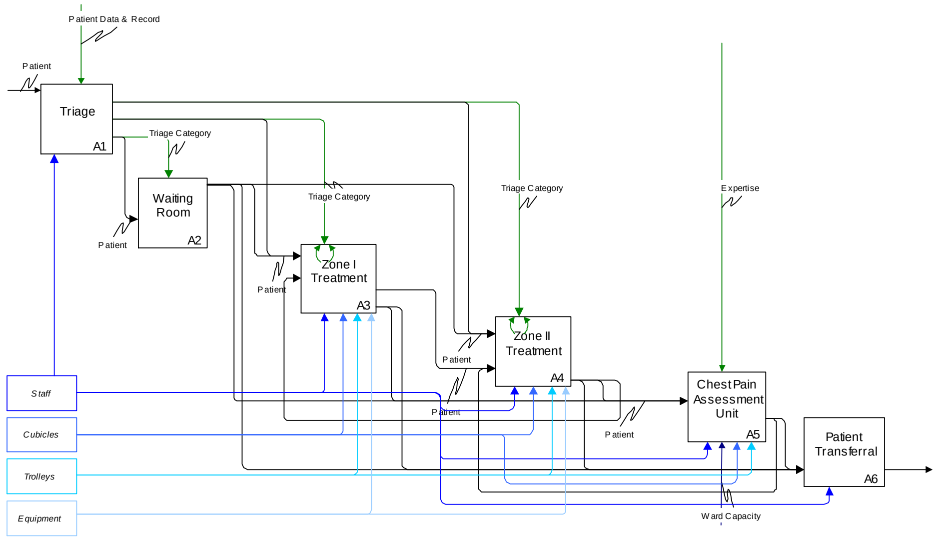
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Triage

In cases of chest pain the patient is triaged on the first sight. The triage procedure is done by the rapid assessment team (RAT). The patient is assessed onto the accident and a patient record is being made. The details obtained from the patient are then handed to the administrational staff. Blood samples are taken as soon as the patient is in a safe environment. The administrational staff is then arranging an appointment for X-Ray. All the findings and diagnostic results are stored in a patient record.



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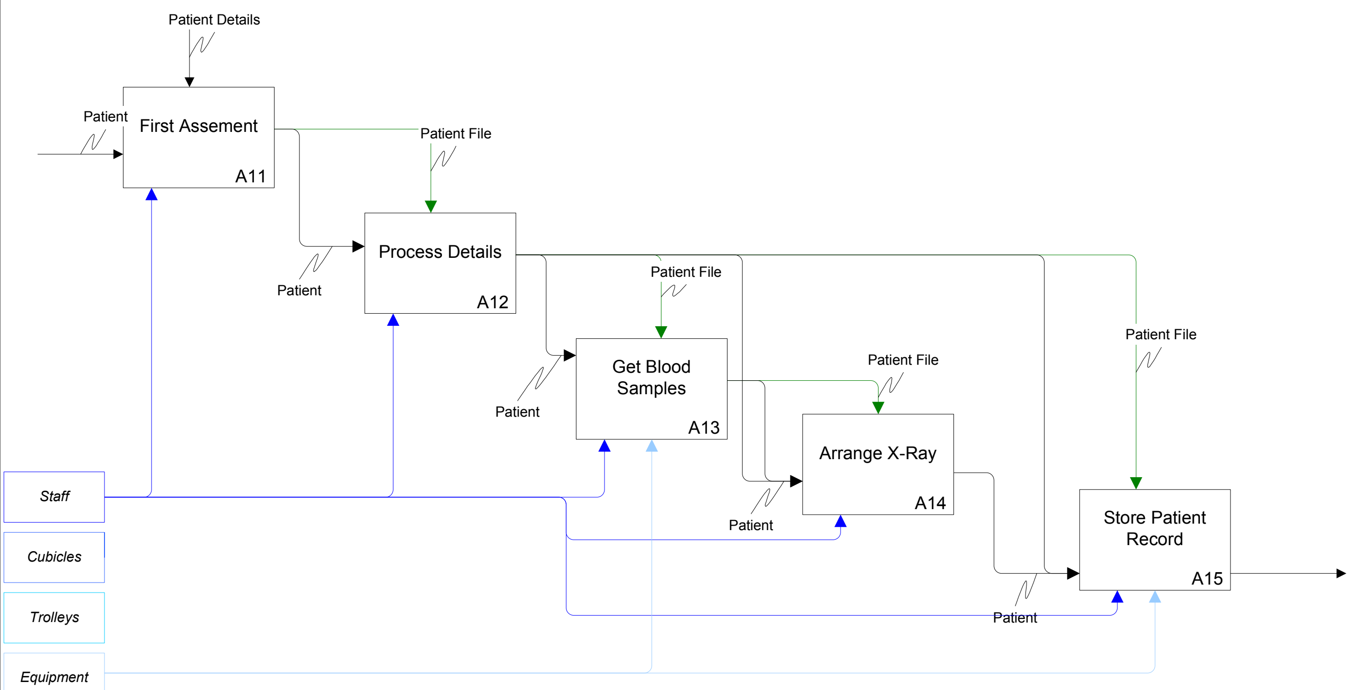

NODE: A1	TITLE: Triage A1	NO.: 2

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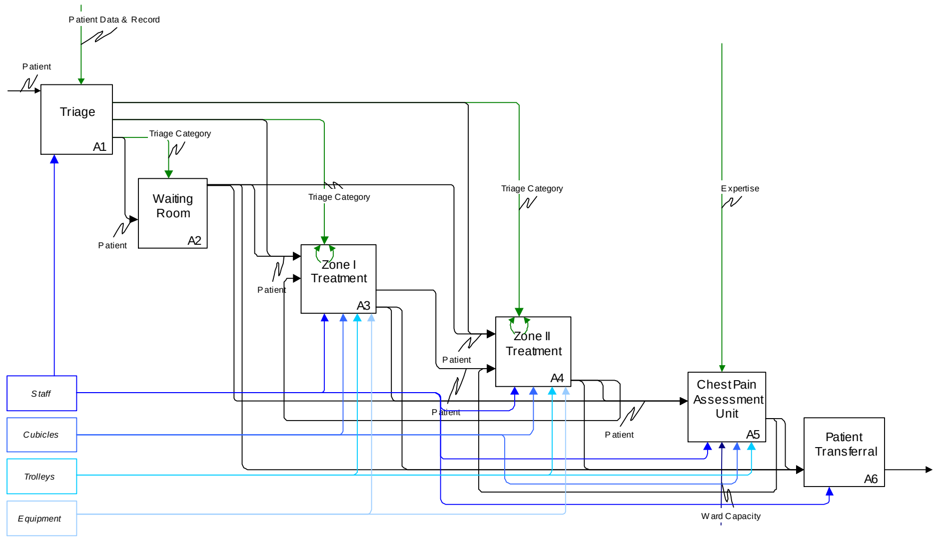
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Waiting Room

In low severe cases and full capacity of the ED the patient will be sent back to the waiting room. Patient waits for X-Ray. After X-Ray the patients have to wait in a preset location to discuss their cases.



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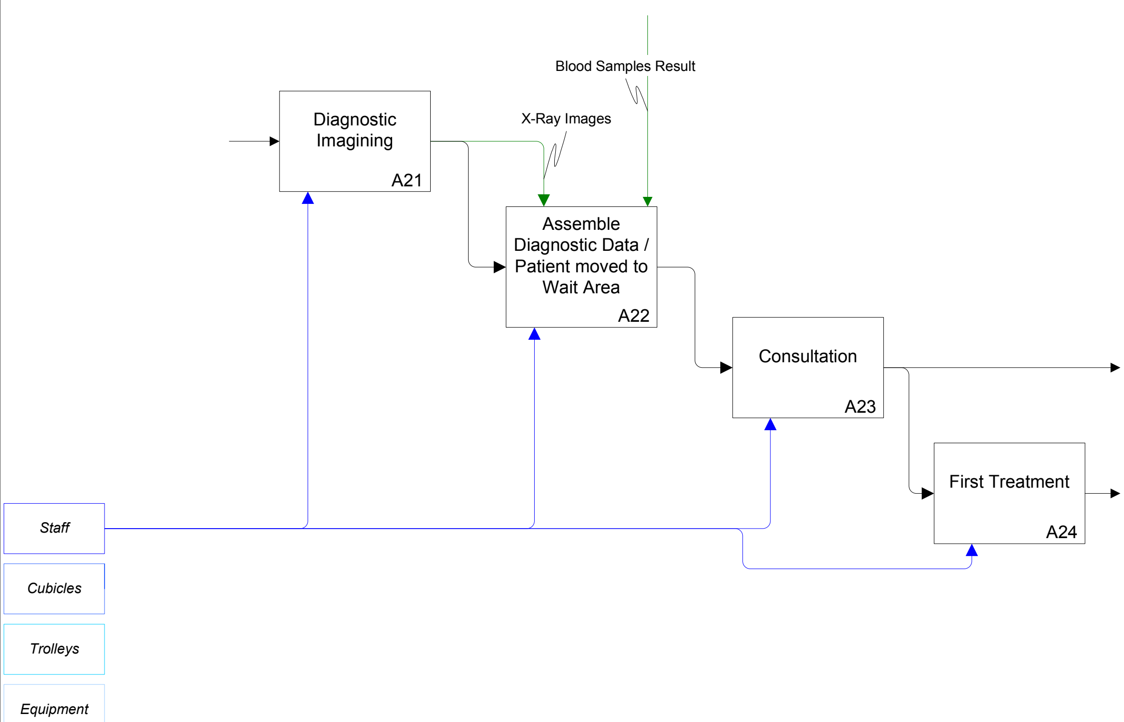

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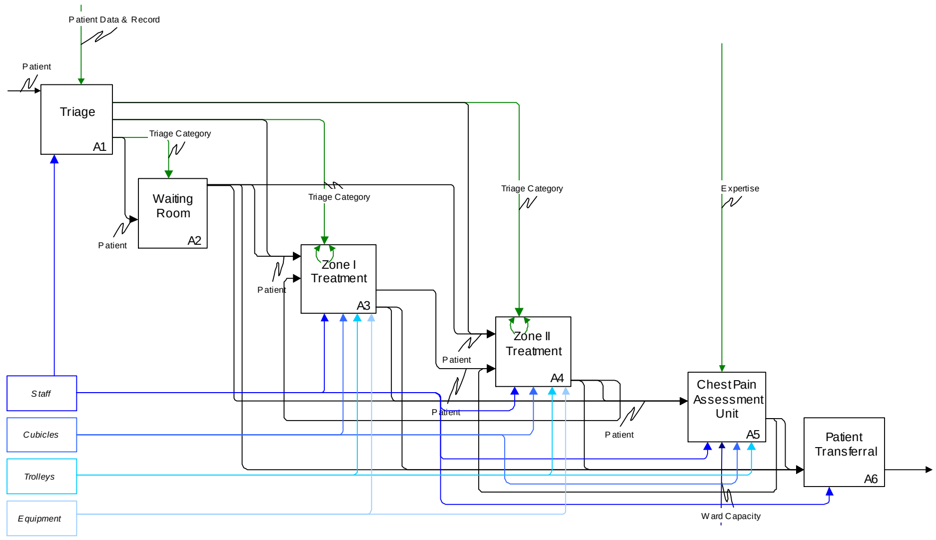
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone I

The Zone I is reserved for Chest Pain patients.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases. As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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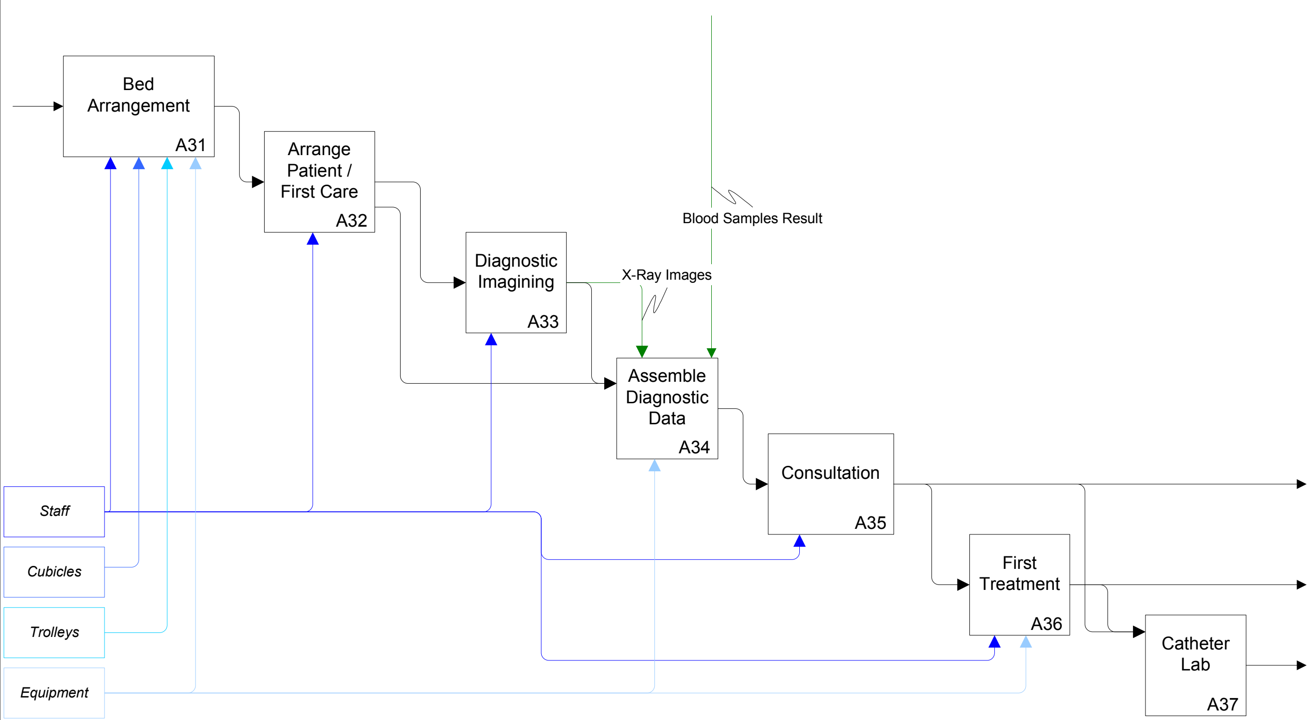

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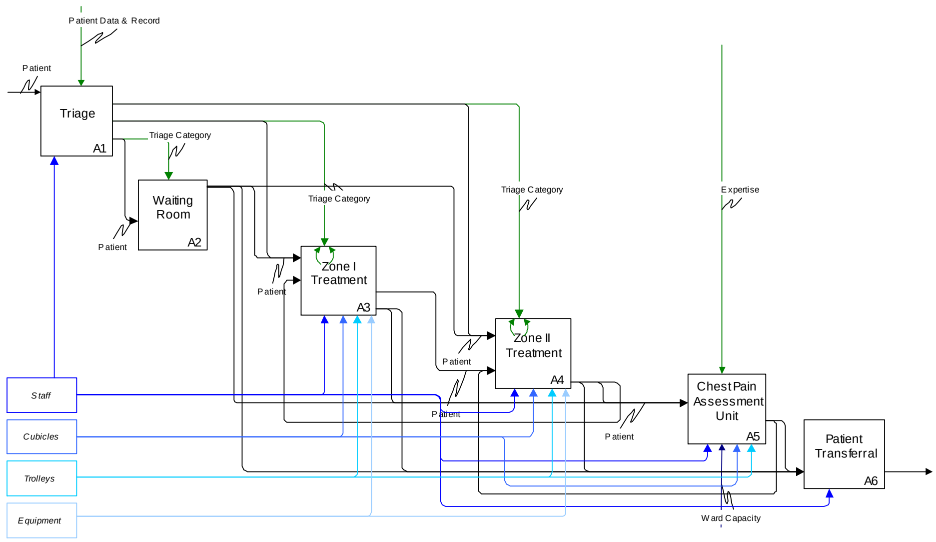
					RECOMMENDED			
	NOTES:				PUBLICATION			

Zone II

As Zone I is dedicated for patients suffering from chest pain, Zone II will only be used in case that there is no space left for the patients in Zone I.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases. As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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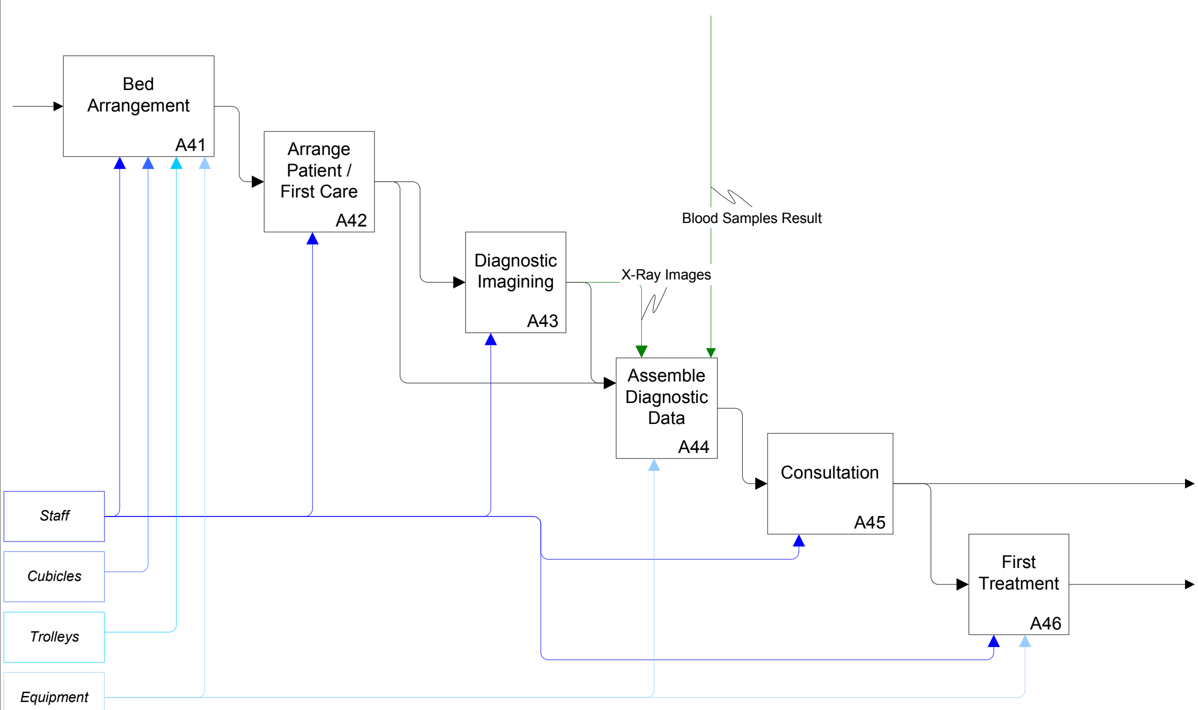

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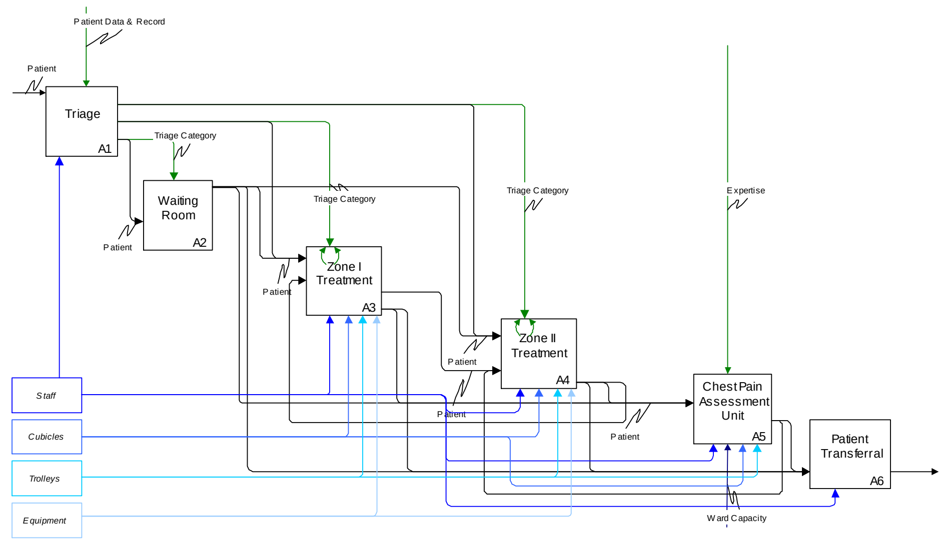
Chest Pain Assessment Unit

The Chest Pain Assessment Unit (CPAU) is a decision unit, which decides the best future treatment for the patient.



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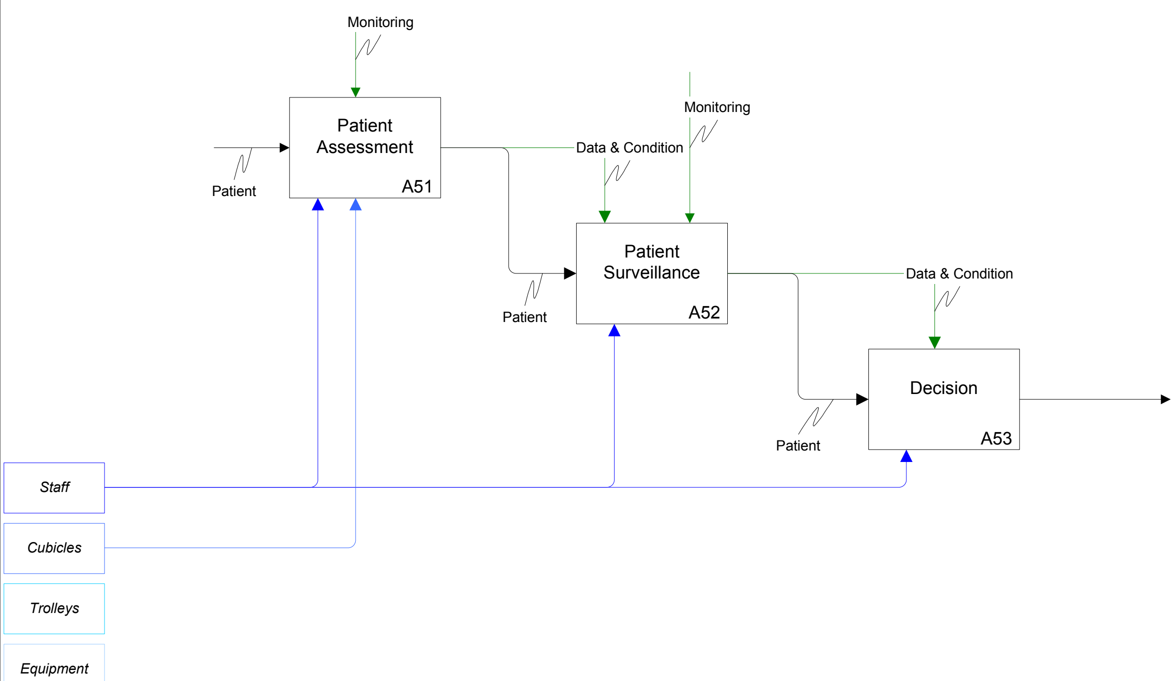

NODE: A5	TITLE: Chest Pain Assessment Unit A5	NO.: 2

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ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
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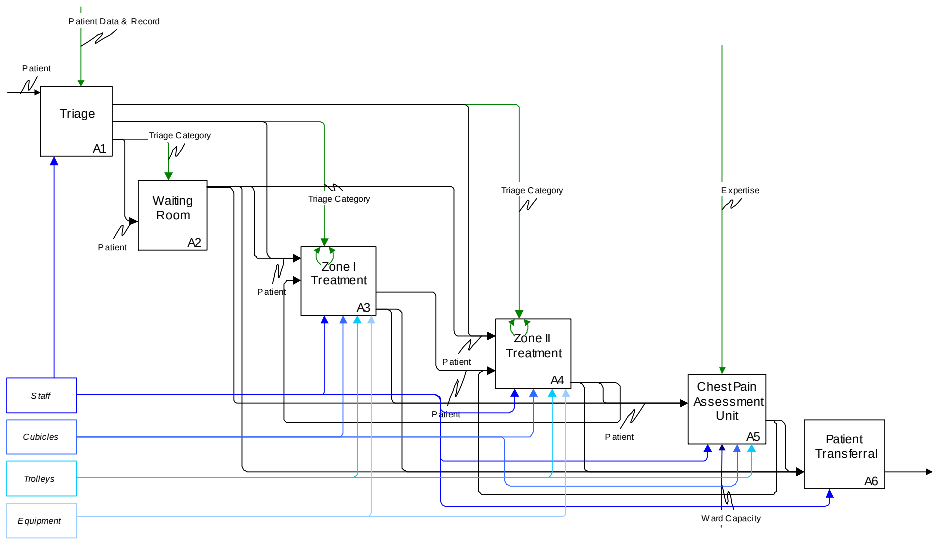
	NOTES:			PUBLICATION			

Patient Transferral

Before any patient is ready to leave the ED, the patient record will be updated. The patient will either be transferred to a ward, the coronary care unit (CCU) or in case of stable condition be sent home.

In case of low severity the patient will either wait in the cubicle or be moved to the corridor. In order to free up a cubicle the patients are moved to the corridor at the end of Zone I, where they wait to be warded. Nurses usually look after the patient who are supposed to leave the hospital until they will be collected or driven home.

Patients moving to the CCU are directly moved to the unit with a minimum of delay.



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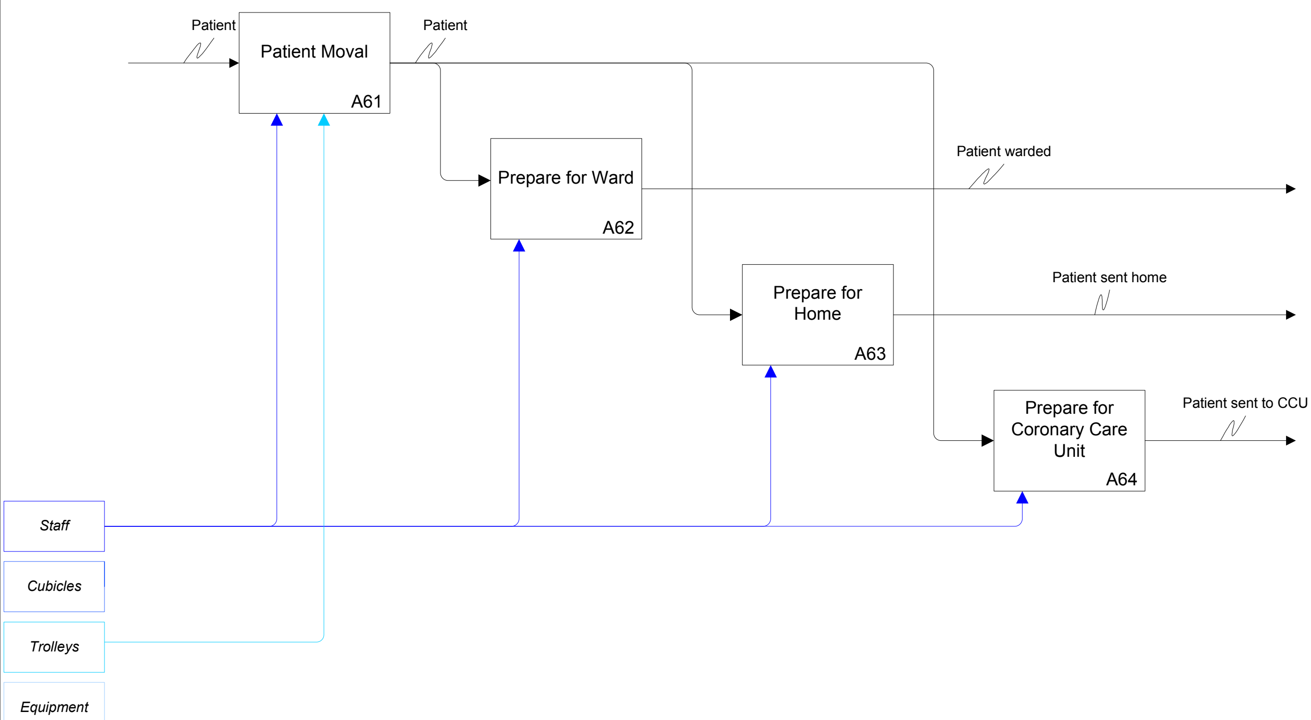

NODE: A6	TITLE: Patient Transferal A6	NO.: 2

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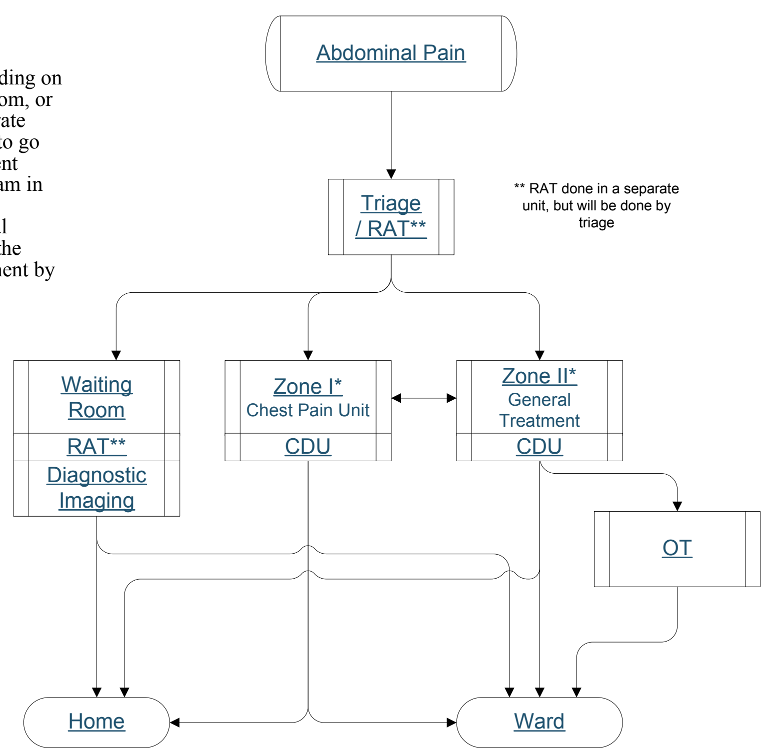
Patients with abdominal pain

Patients with abdominal pain are triaged in the triage area. Depending on the triage category the patient is either sent back to the waiting room, or to either Zone I or II. The rapid assessment team (RAT) is a separate team which replacing the triage procedure in case the patient has to go straight to either one of the Zones. The RAT is assessing the patient similar to the triage team. (The RAT will be done by the triage team in future.)
Patients that require immediate treatment are operated by a special surgeon, who is available on call. Depending on the condition of the patient the patient is either warded or sent home for further treatment by their local GP.



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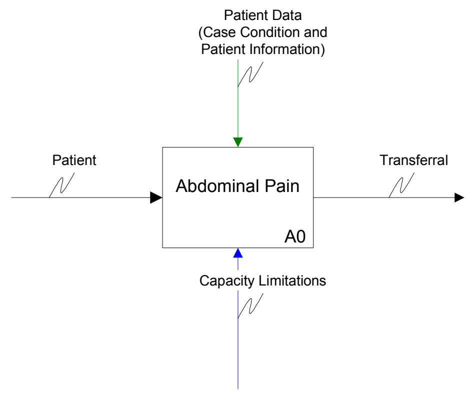

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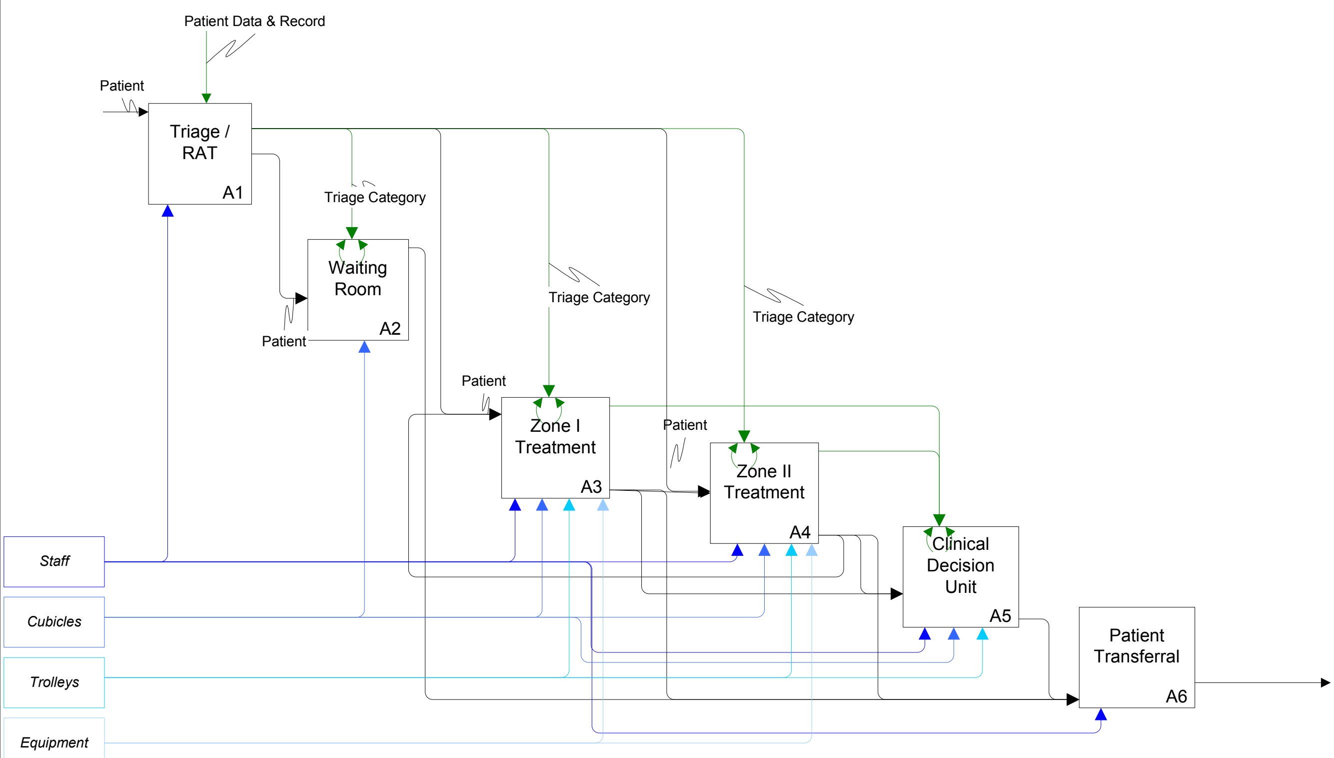

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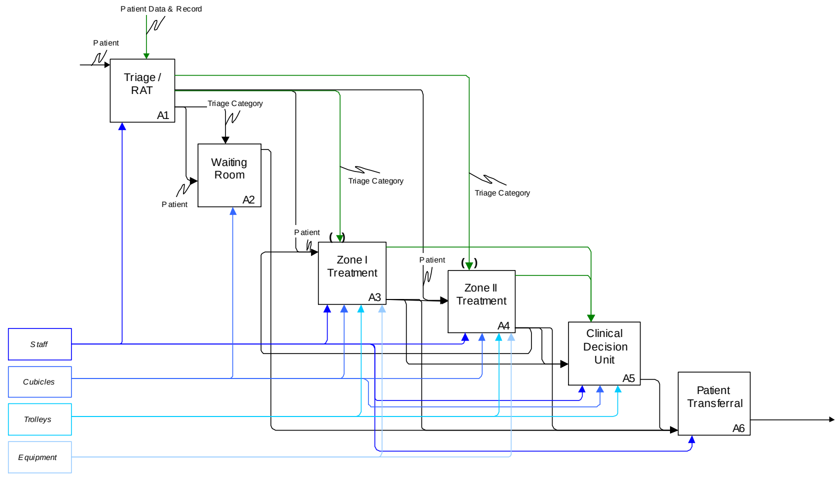
				RECOMMENDED			
	NOTES:			PUBLICATION			

Triage

The triage procedure for abdominal pain is done either by the triage team or by the rapid assessment team (RAT). The patient is assessed based on the nature of his case and a patient record is generated. The details obtained from the patient are then handed to the administrational staff. The triage team decides whether blood samples or X-Ray Images are needed. Blood samples are taken as soon as the patient is in a safe environment. The administrational staff is then arranging an appointment for X-Ray. All the findings and diagnostic results are stored in a patient record.



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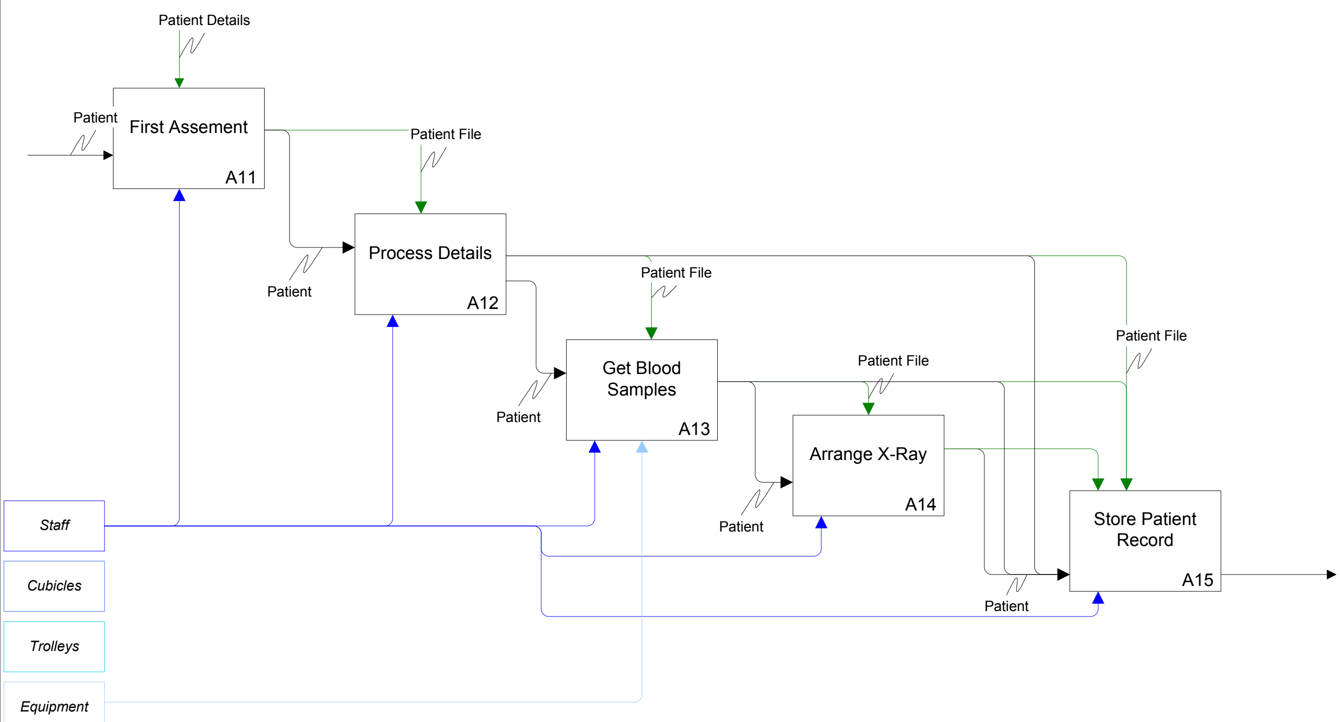

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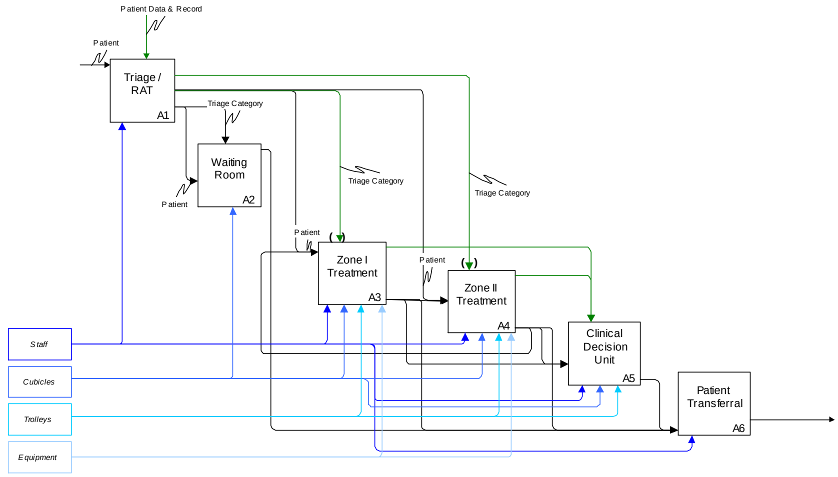
Waiting Room

In low severe cases and full capacity of the ED the patient will be sent back to the waiting room. Patient waits for X-Ray. After X-Ray the patients have to wait in a preset location to discuss their cases.



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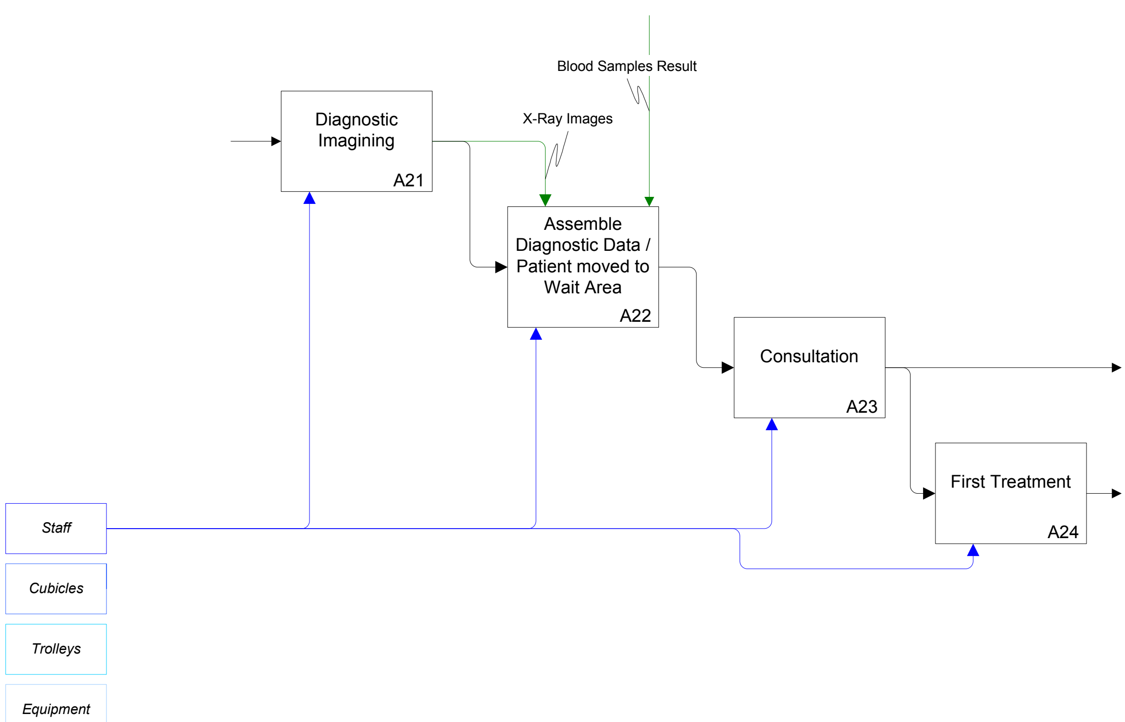

NODE: A2	TITLE: Zone I Treatment A2	NO.: 3

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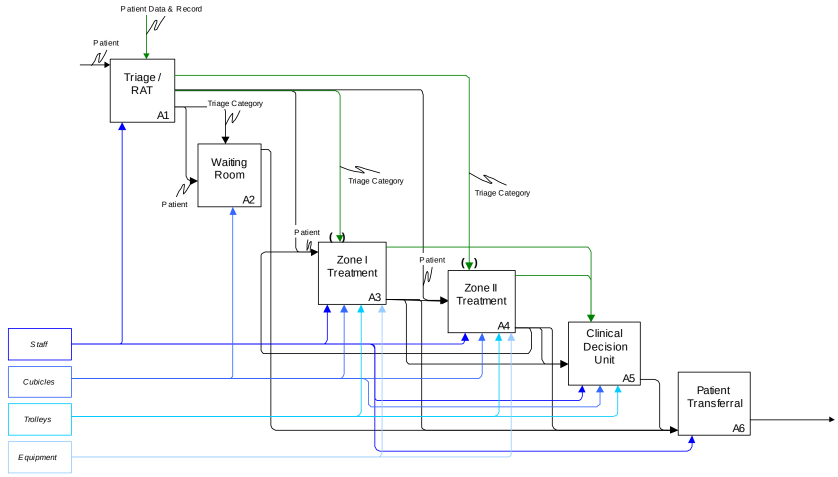
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone I

The Zone I is reserved for Chest Pain patients.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases. As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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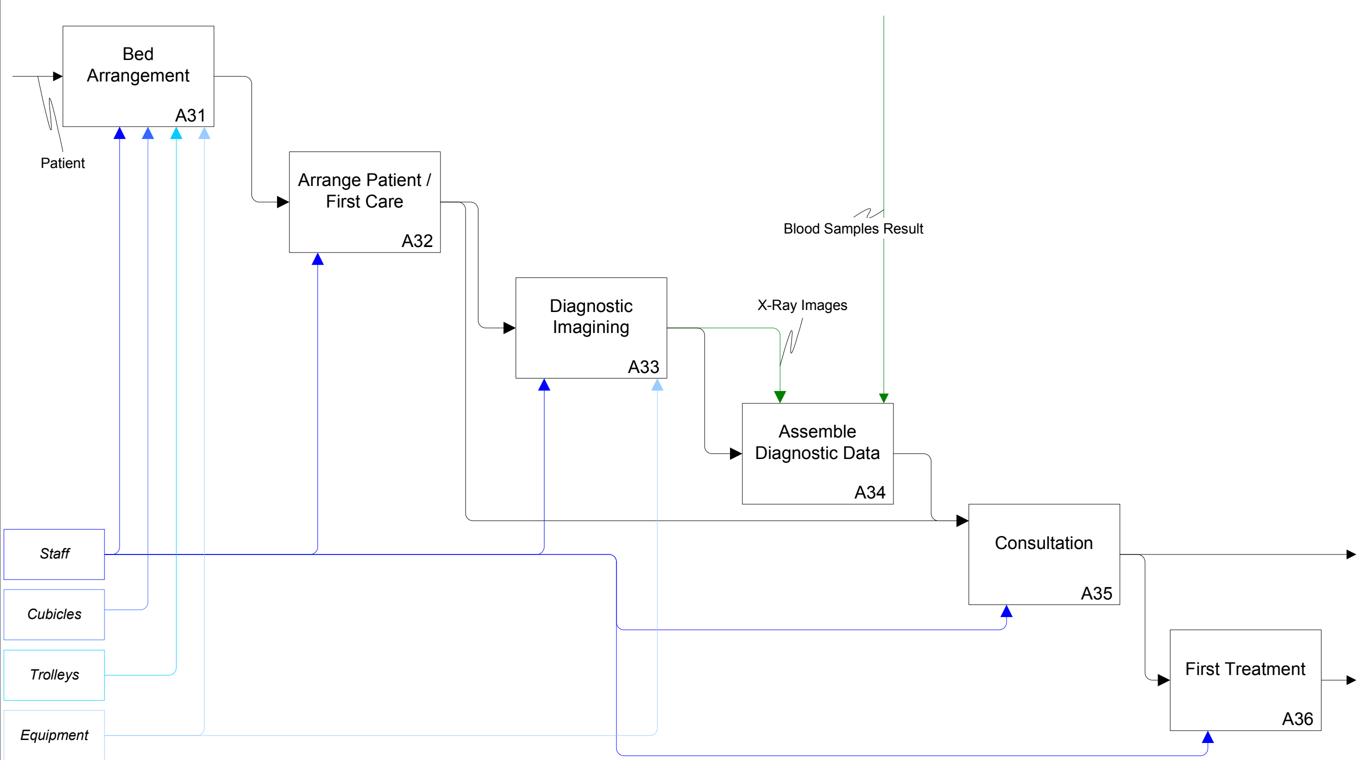

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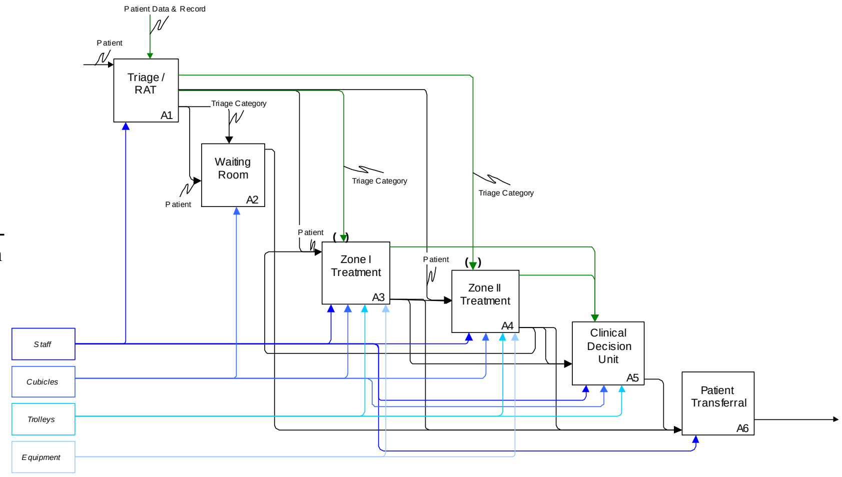
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone II

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases. As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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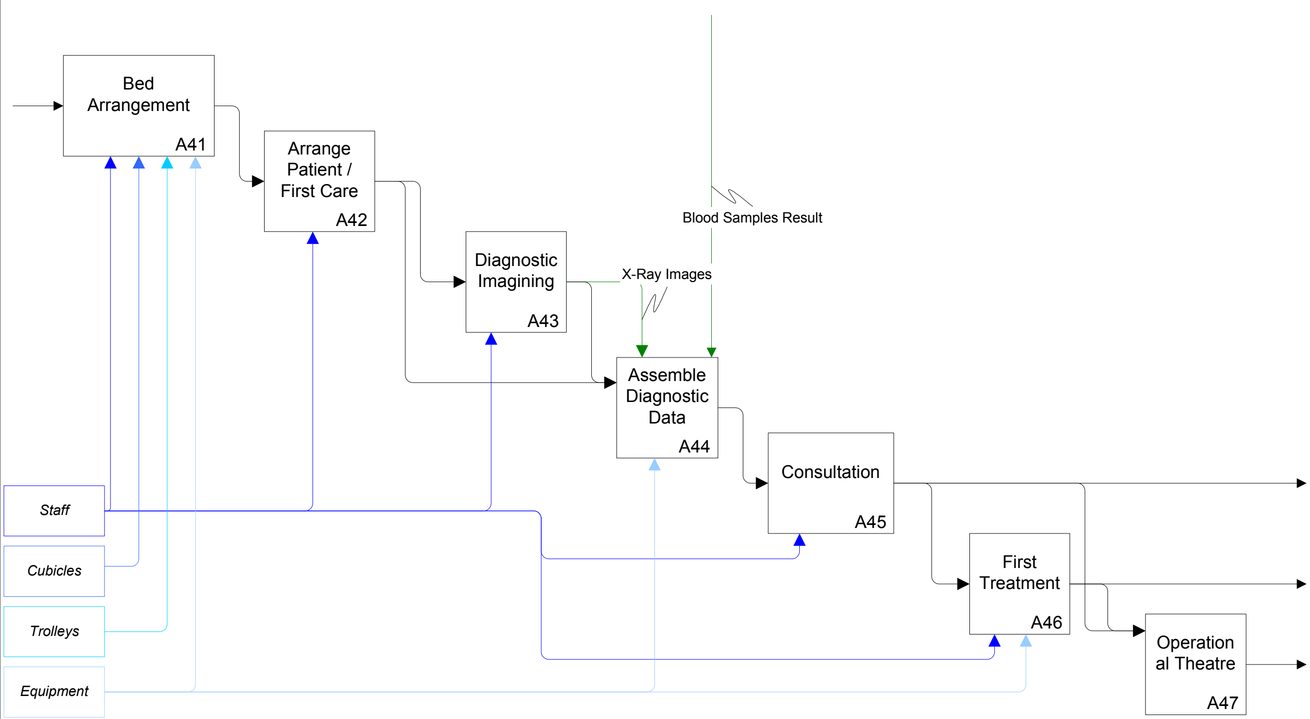
	NOTES:			PUBLICATION			

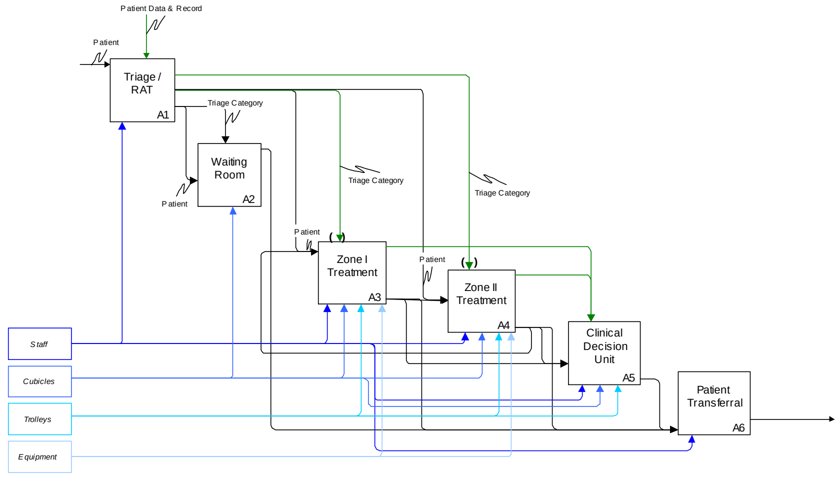


NODE: A4	TITLE: Zone II Treatment A4	NO.: 3

USED AT:	AUTHOR:	DATE:	17/04/2008	X	WORKING	READER	DATE	CONTEXT:
ED in SVUH	PROJECT: PM of ED@SVUH	REV.:	2.0		DRAFT			
					RECOMMENDED			
	NOTES:				PUBLICATION			

Clinical Decision Unit

The Clinical Decision Unit (CDU) where the final decision is made whether to hospitalize the patients or sent them home. The decision is subject to patient condition and results from a considerable monitoring for the case status.



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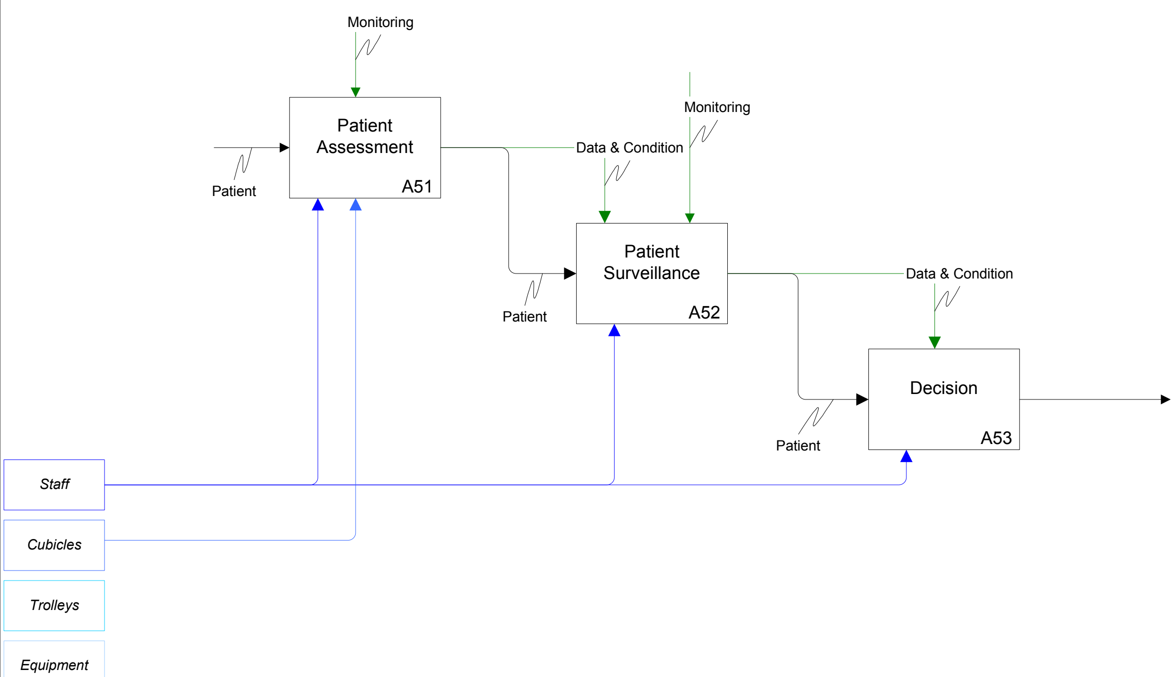

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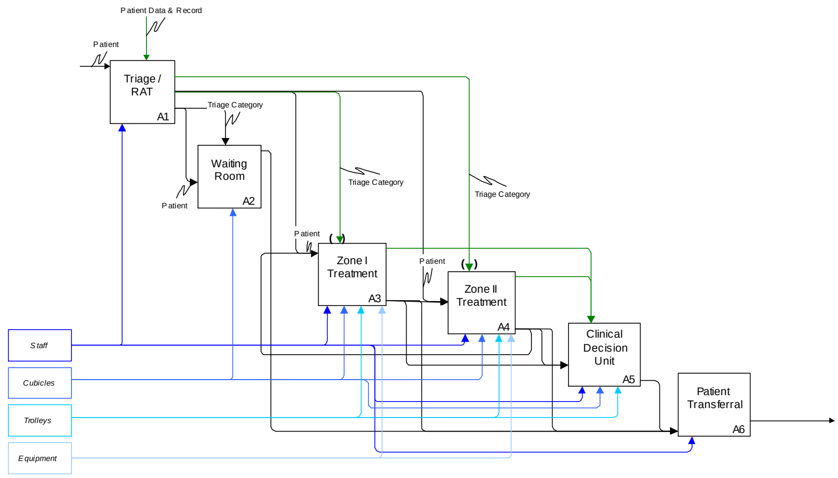
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Patient Transferral

Before any patient is ready to leave the ED, the patient record will be updated. The patient will either wait in his cubicle or moved to the corridor to free up a cubicle. Nurses usually look after the patient who are supposed to leave the hospital until they will be collected or driven home.



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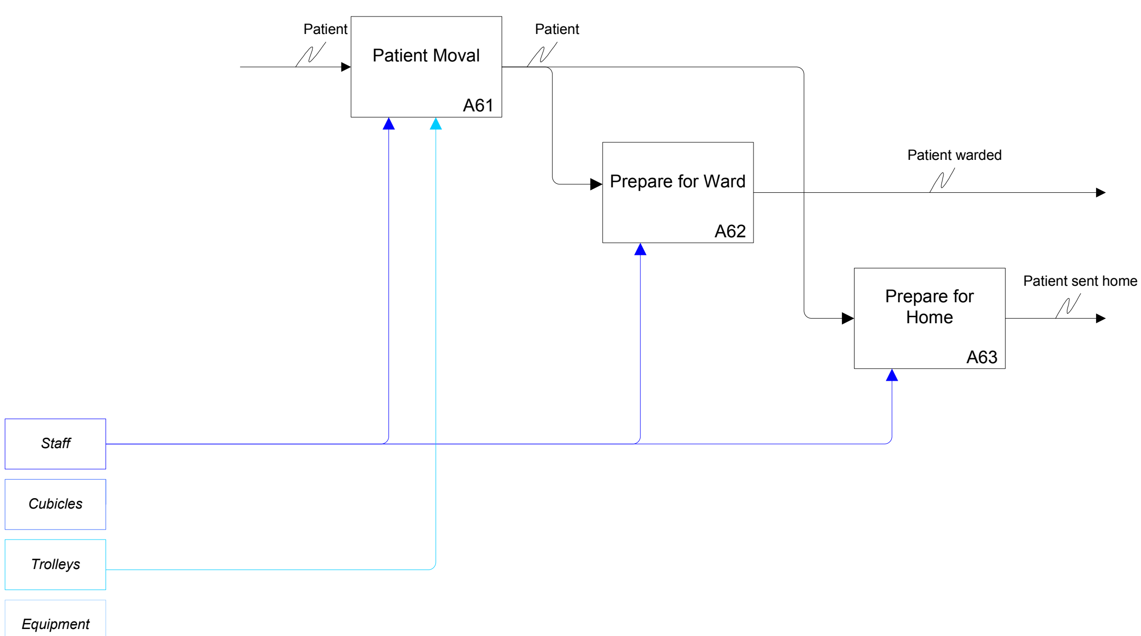

NODE: A6	TITLE: Patient Transferal A6	NO.: 3

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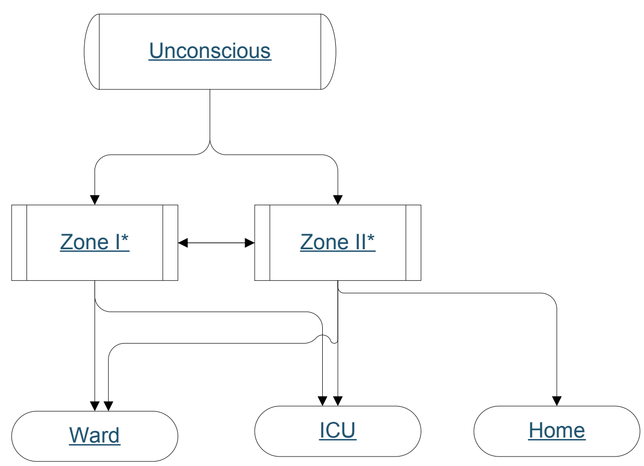
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Unconscious patients

Unconscious patients are placed directly in Zone I or II. Triage is being skipped or done by the rapid assessment team (RAT). All assessments in order to gather as much information as possible. Depending on the diagnosis, the patient will either be placed in the ICU, ward or sent home whenever he is in a safe condition.



NODE: A-0	TITLE: Unconciousness A-0	NO.: 4

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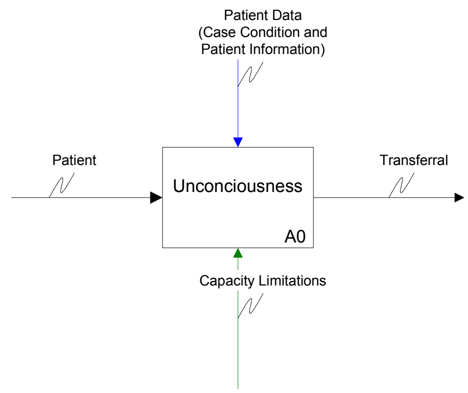

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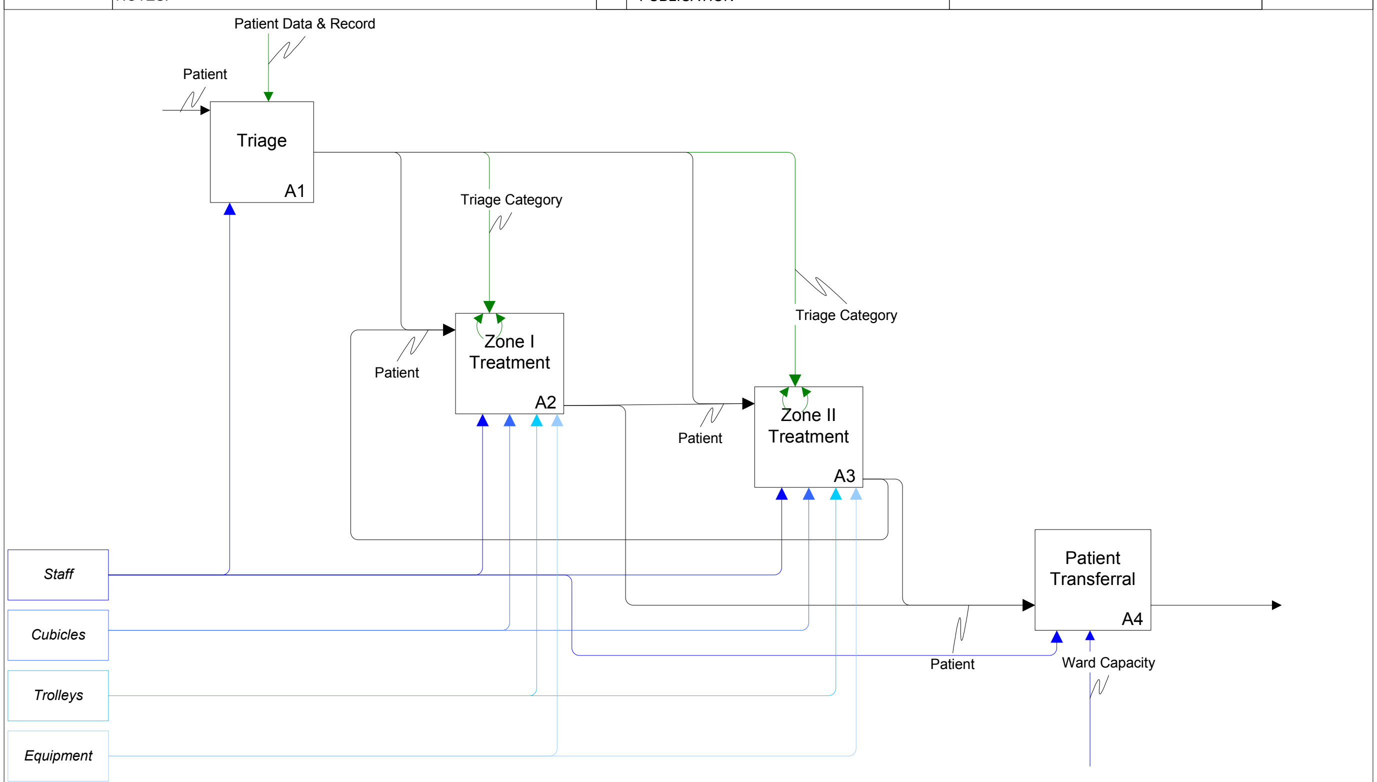

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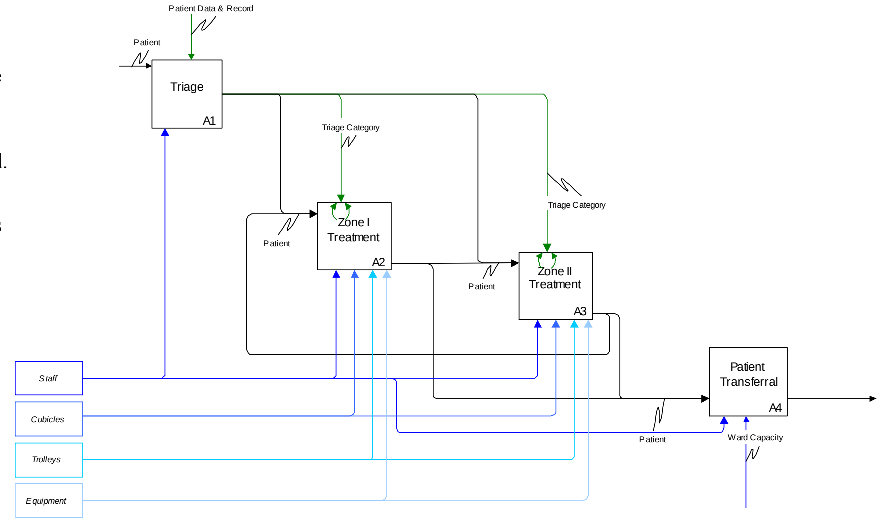
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Triage

The aid of witnesses/relatives is required to triage unconscious patients. The patient is assessed onto the nature of his case and a patient record is made. The details obtained from the patient or relatives are then handed to the administrational staff. The triage team decides whether blood samples or X-Rays are needed. Blood samples are taken as soon as the patient is in a safe environment. The administrational staff is then arranging an appointment for X-Ray. All the findings and diagnostic results are stored in a patient record.



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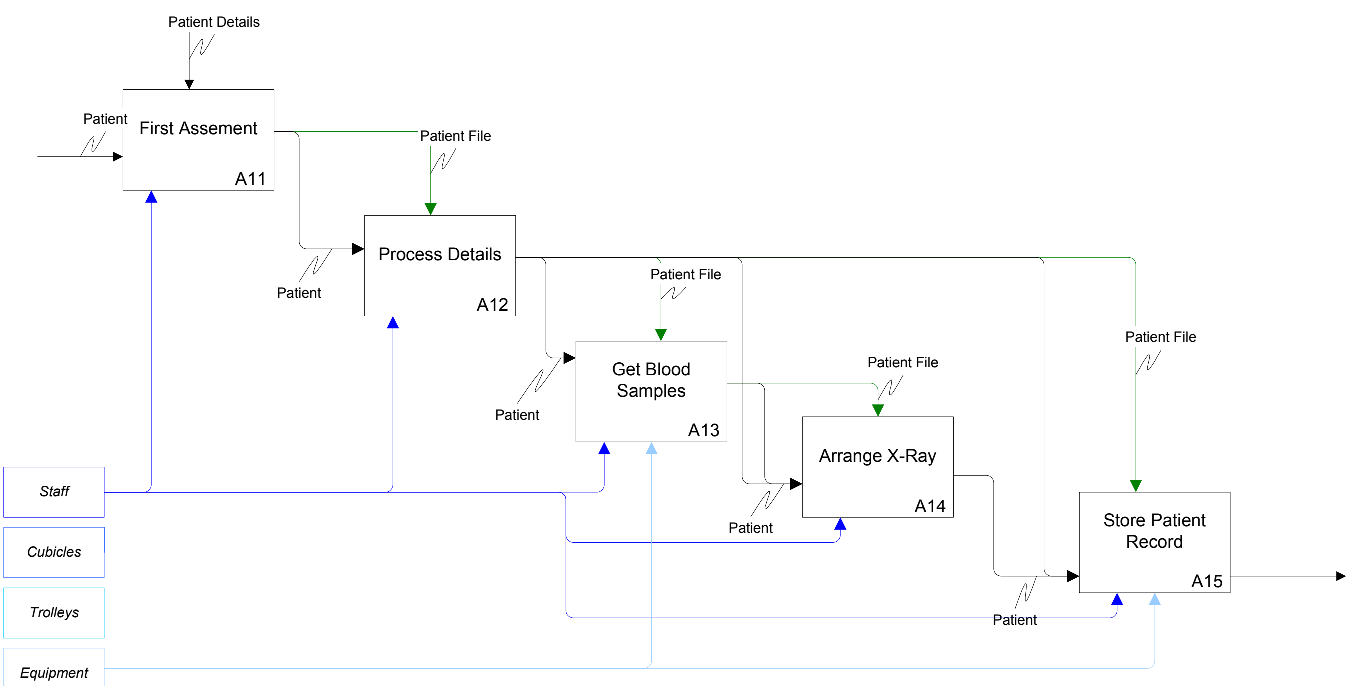

NODE: A1	TITLE: Triage A1	NO.: 4

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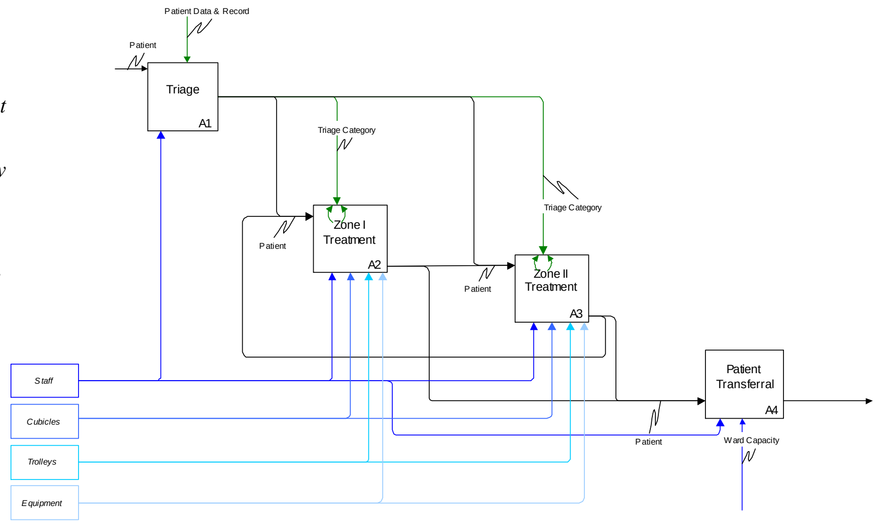
ED in SVUH	PROJECT: PM of ED@SVUH	REV.:	2.0		DRAFT			
					RECOMMENDED			
	NOTES:				PUBLICATION			

Zone I

The Zone I is reserved for Chest Pain patients.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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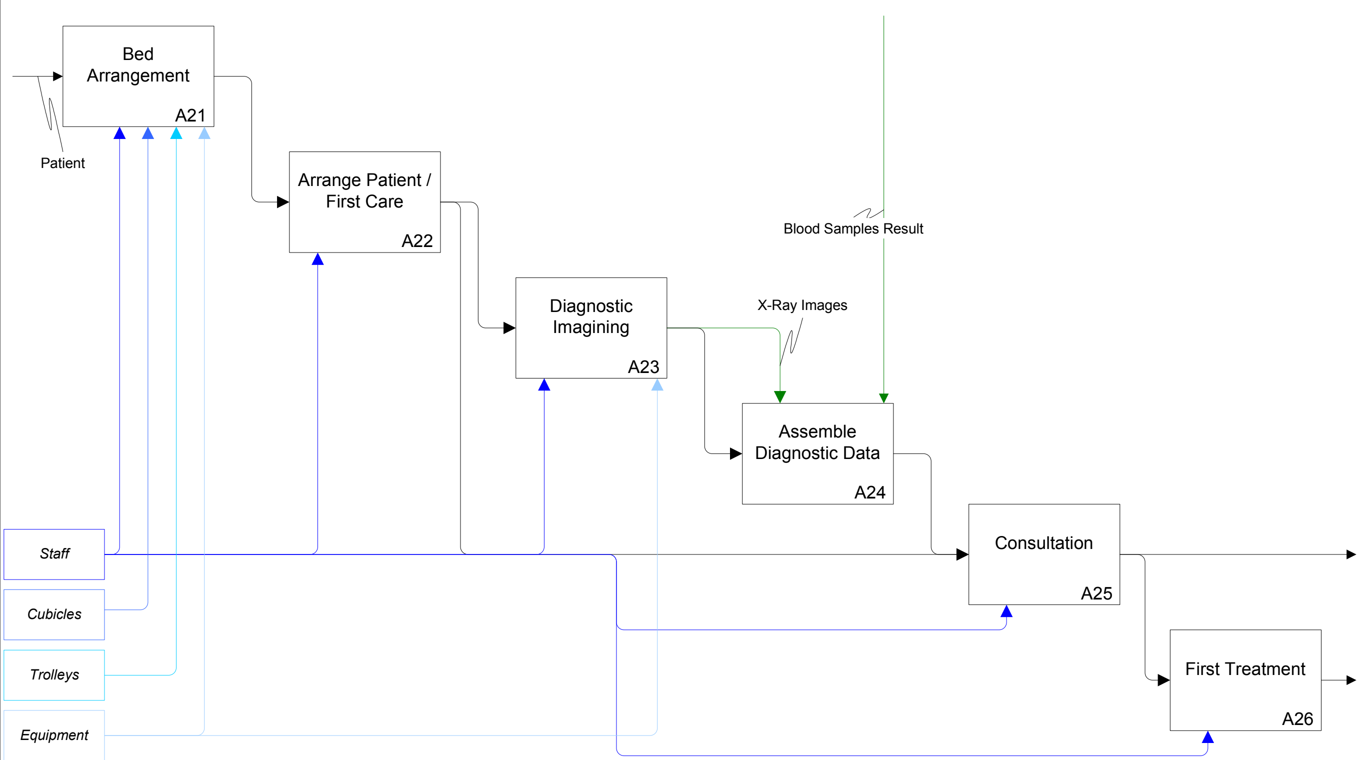
	NOTES:				PUBLICATION			



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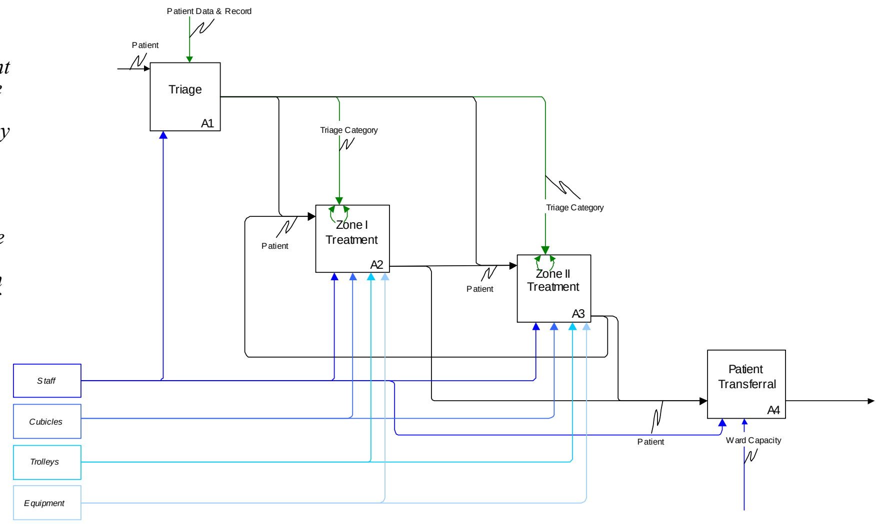
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone II

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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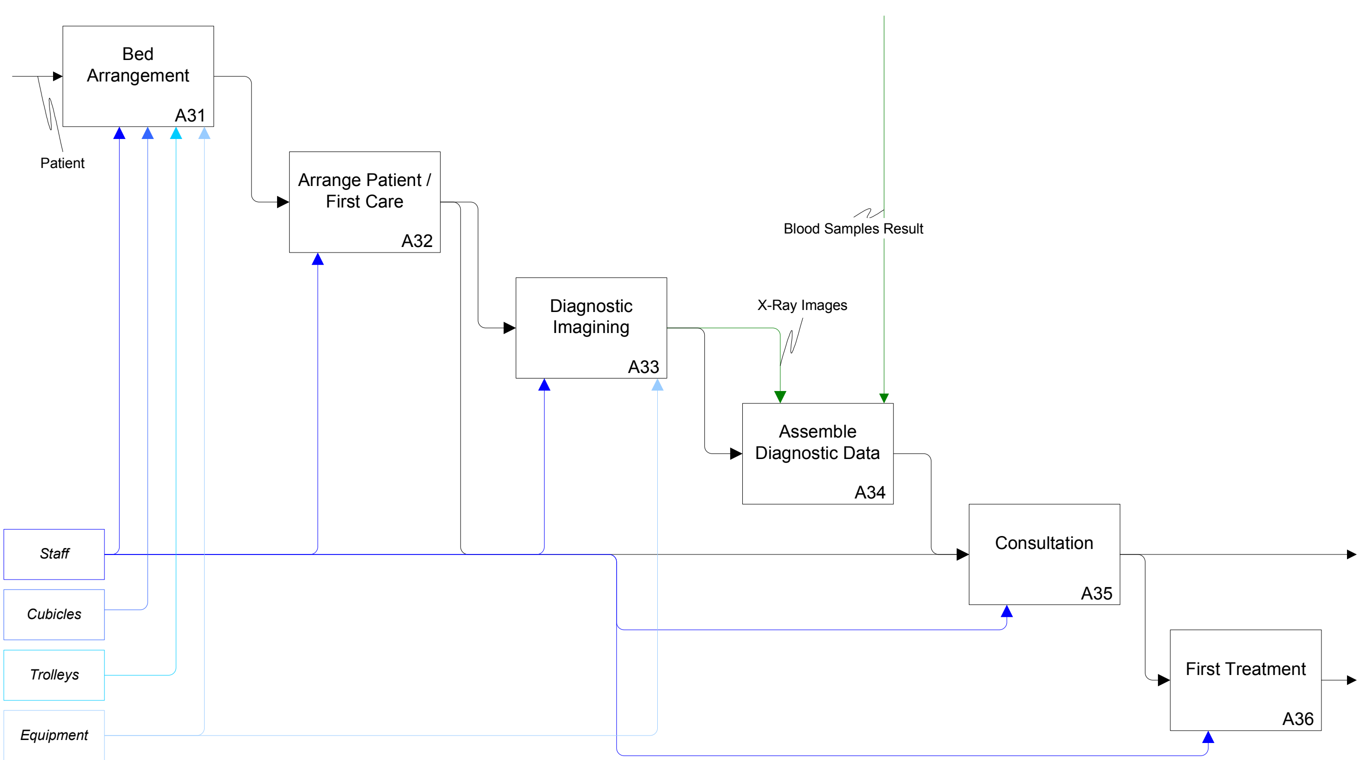

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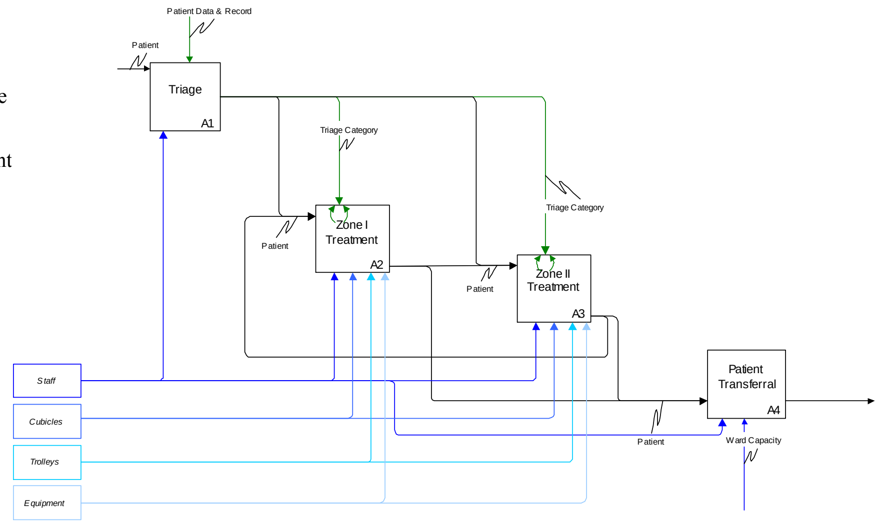
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Patient Transferral

In case that the patient is remaining unconscious, he will be transferred to the ICU immediately. Otherwise he will be assessed on his current condition.

Before any patient is ready to leave the ED, the patient record will be updated. The patient will either wait in his cubicle or moved to the corridor to free up a cubicle. Nurses usually look after the patient who are supposed to leave the hospital until they will be collected or driven home.



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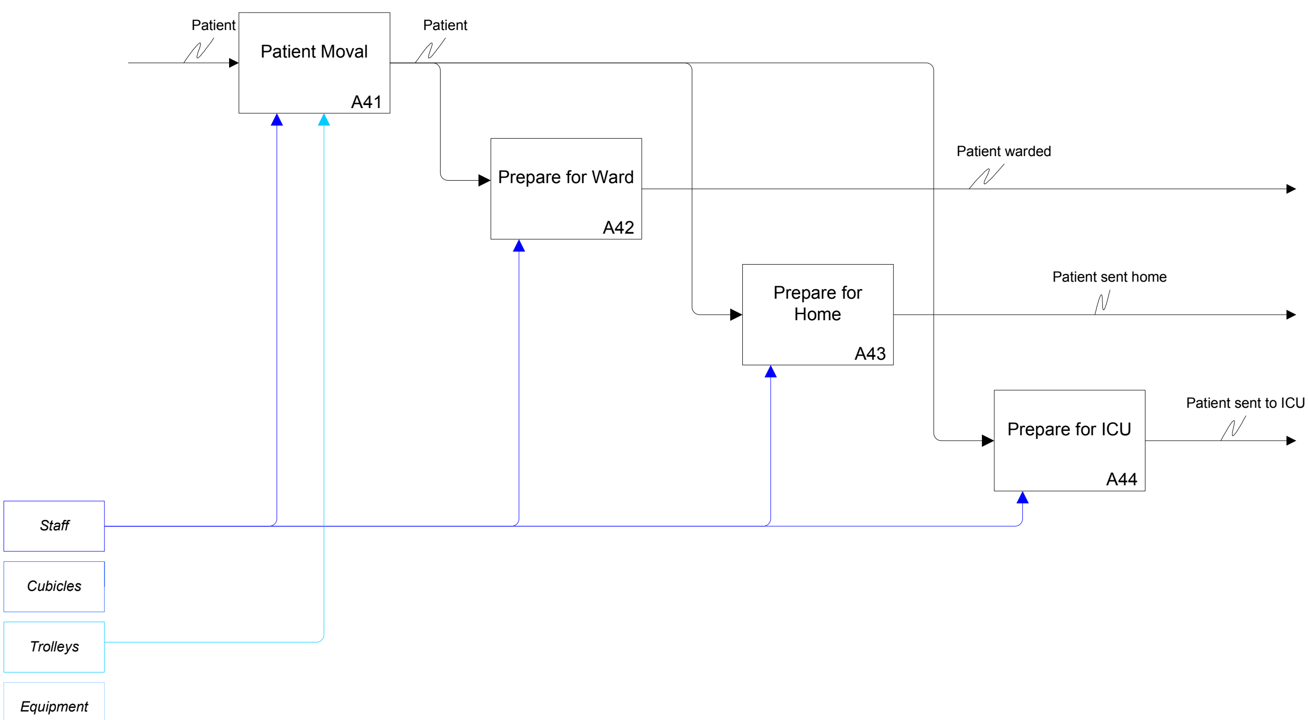

NODE: A4	TITLE: Patient Transferal A4	NO.: 4

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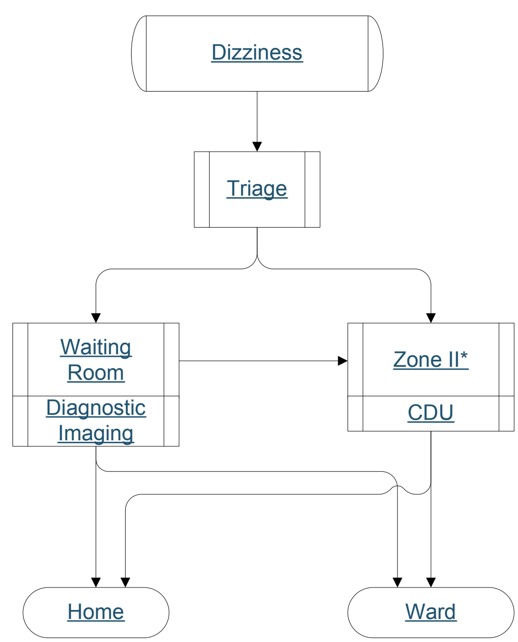
ED in SVUH	PROJECT: PM of ED@SVUH	REV.:	2.0		DRAFT			☐
					RECOMMENDED			
	NOTES:				PUBLICATION			

Patient that are feeling dizzy

Patients that are feeling dizzy are triaged and may be sent back to the waiting room. In severe cases the patients are placed in Zone II. The patients are being assessed, diagnosed and consulted. Depending on their case the patients are getting warded or are sent home, to be treated by their local GP.



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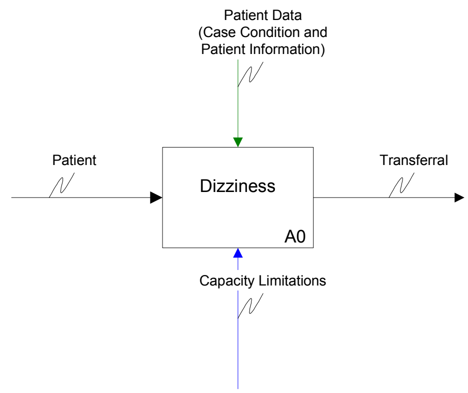

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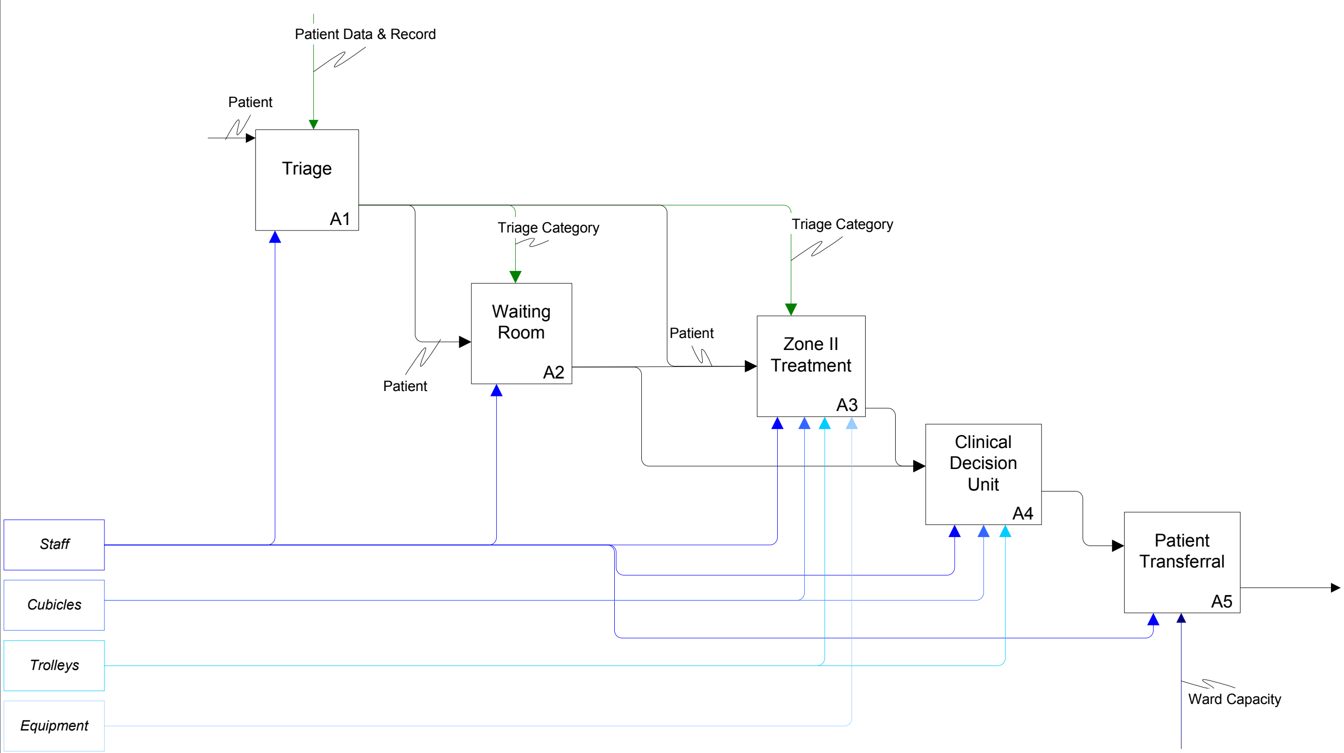

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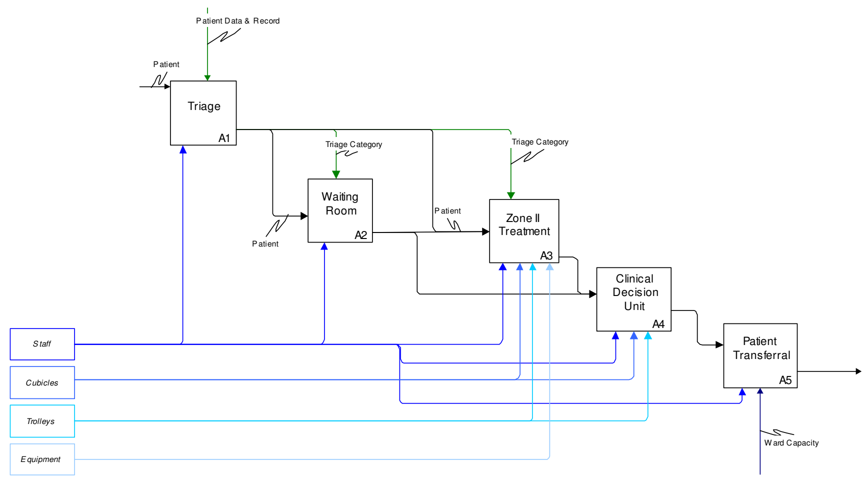
				RECOMMENDED			
	NOTES:			PUBLICATION			

Triage

Patient that feel dizzy are triaged by the triage team. The patient is assessed based on the accident and a patient record is made. The details obtained from the patient are then handed to the administrational staff. Blood samples are taken as soon as the patient is in a safe environment. The administrational staff is then arranging an appointment for X-Ray. All the findings and diagnostic results are stored in a patient record.



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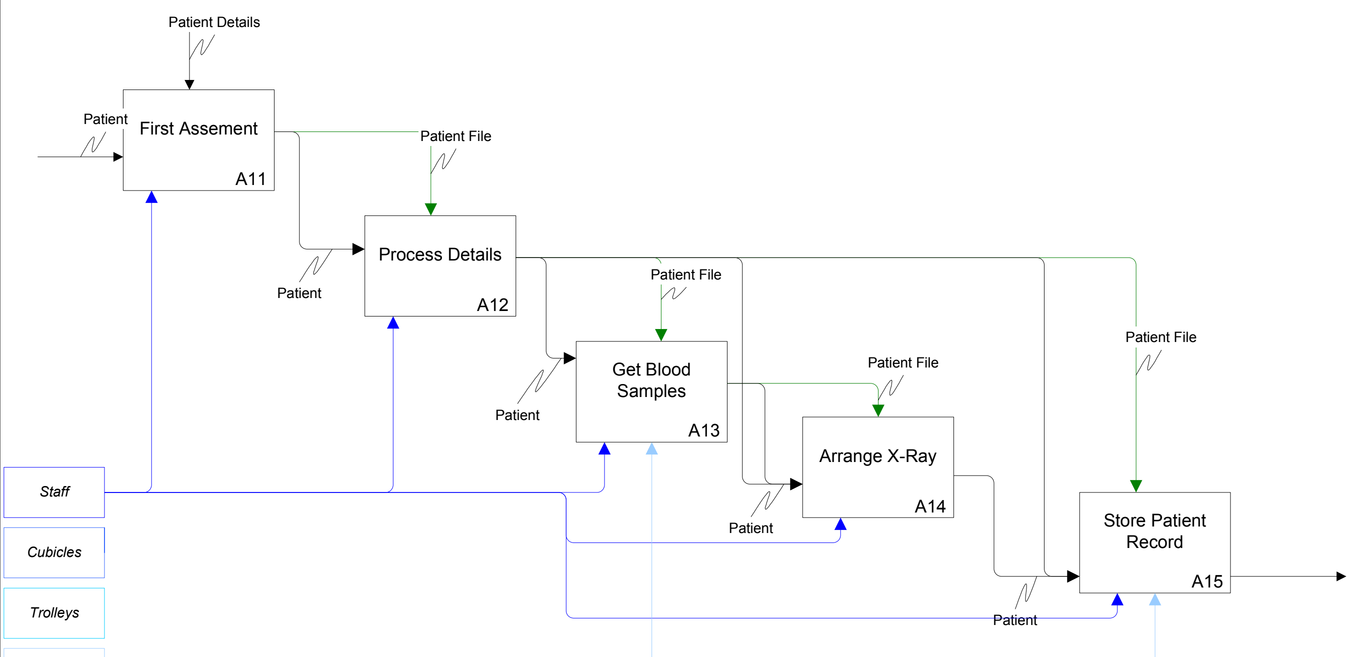

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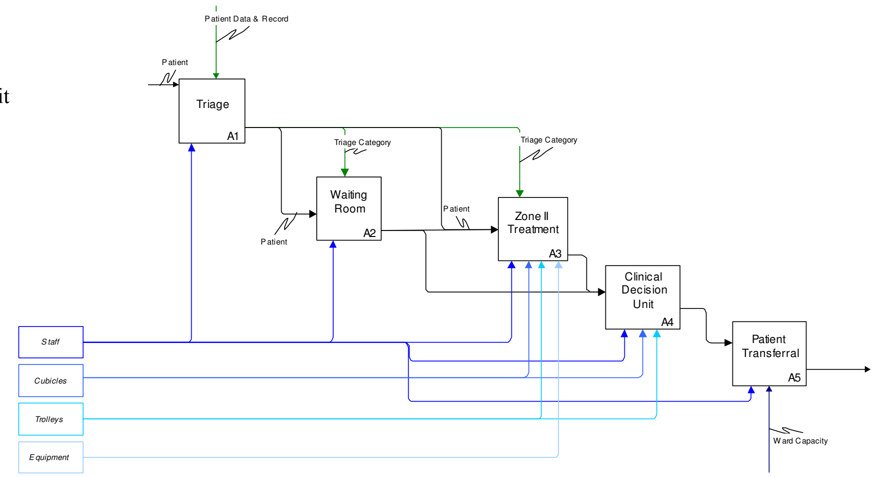
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Waiting Room

In low severe cases and full capacity of the ED the patient will be sent back to the waiting room. Patient waits for X-Ray. After X-Ray the patients have to wait in a preset location to discuss their cases.



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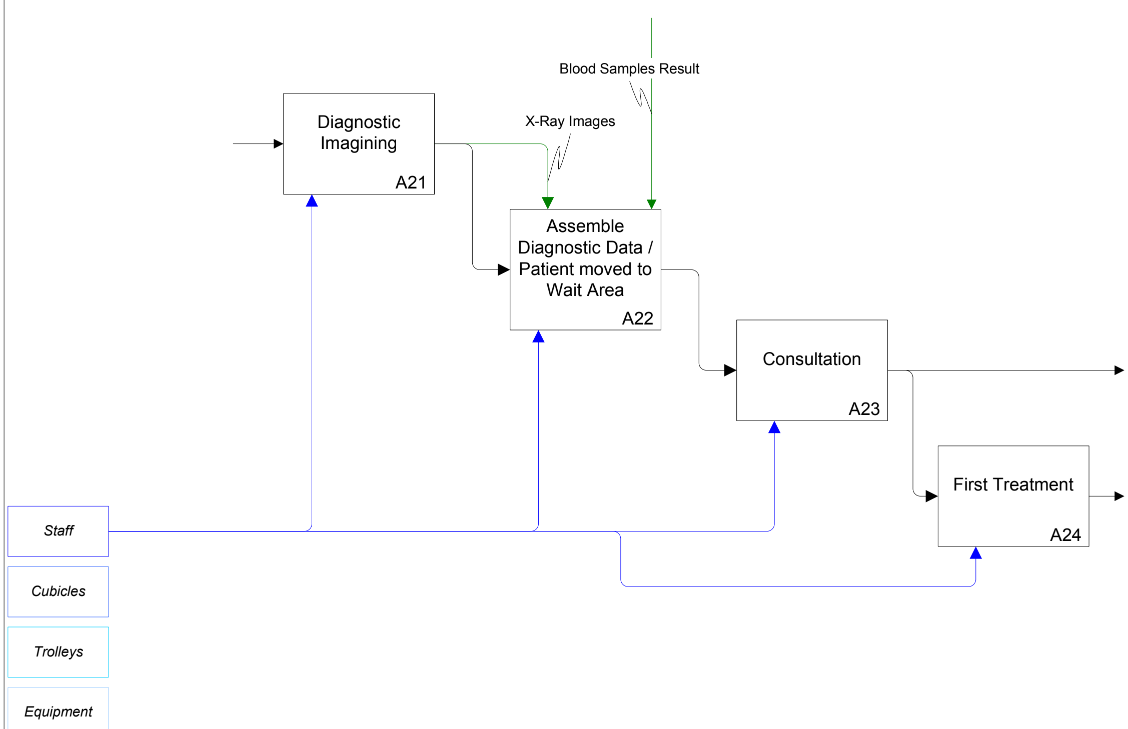

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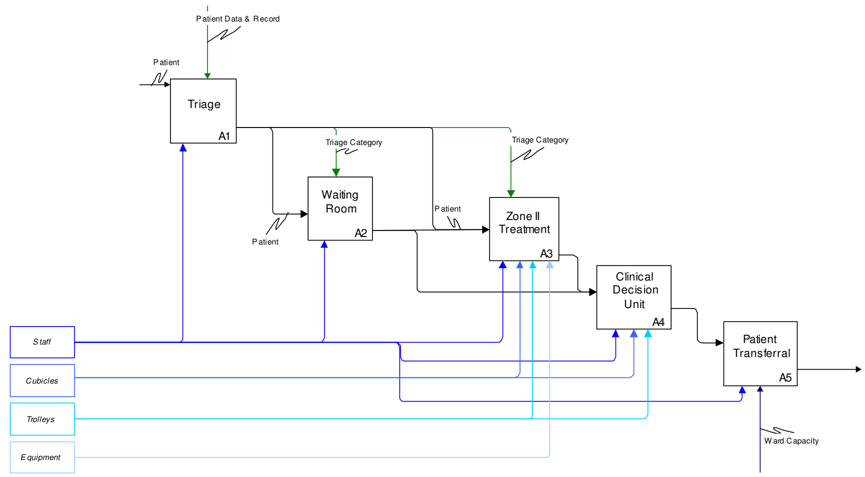
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone II

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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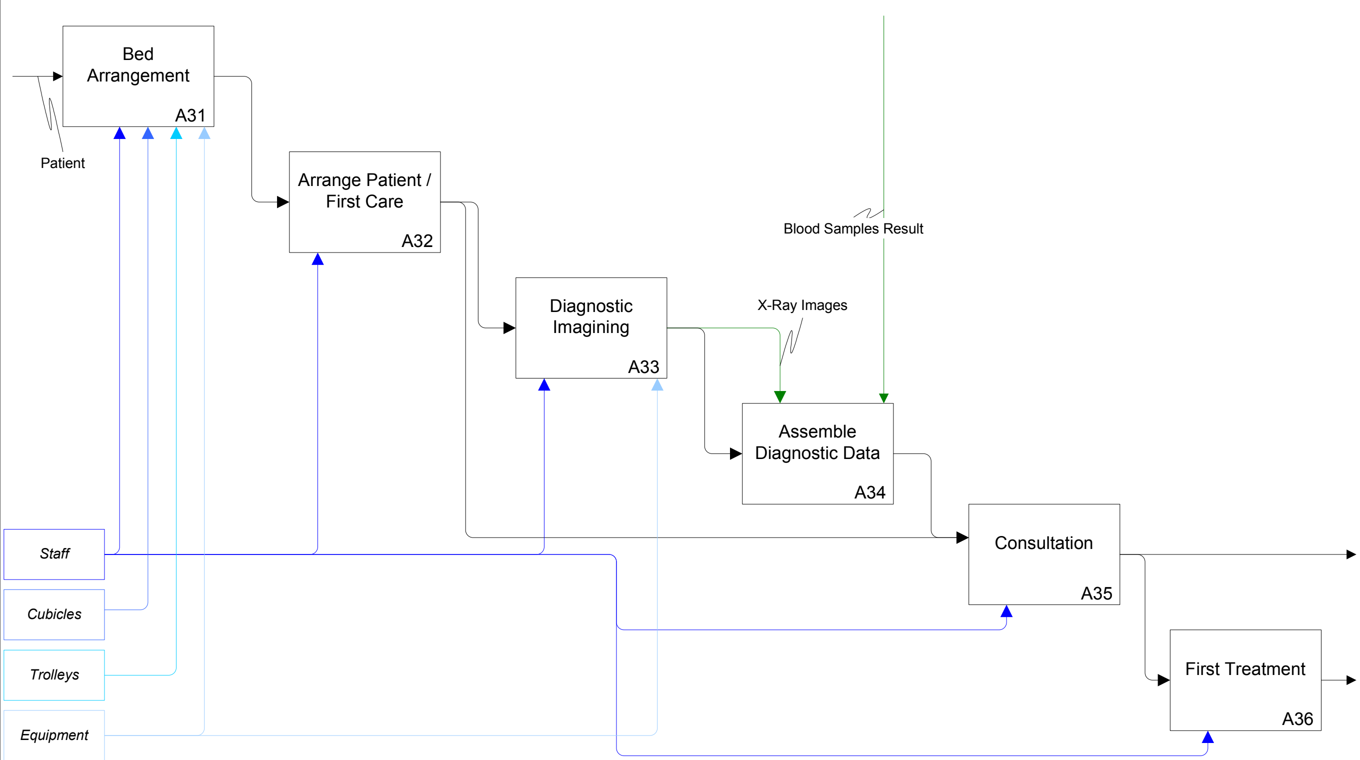

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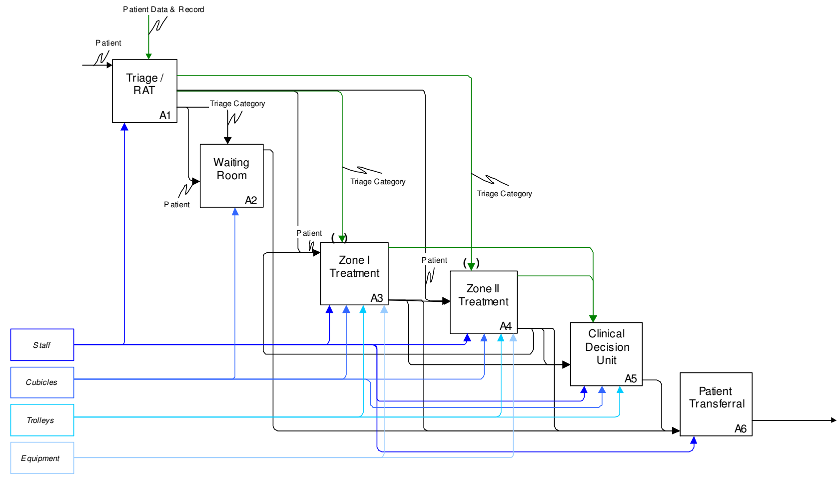
	NOTES:			PUBLICATION			

Clinical Decision Unit

The Clinical Decision Unit (CDU) where the final decision is made whether to hospitalize the patients or sent them home. The decision is subject to patient condition and results from a considerable monitoring for the case status.



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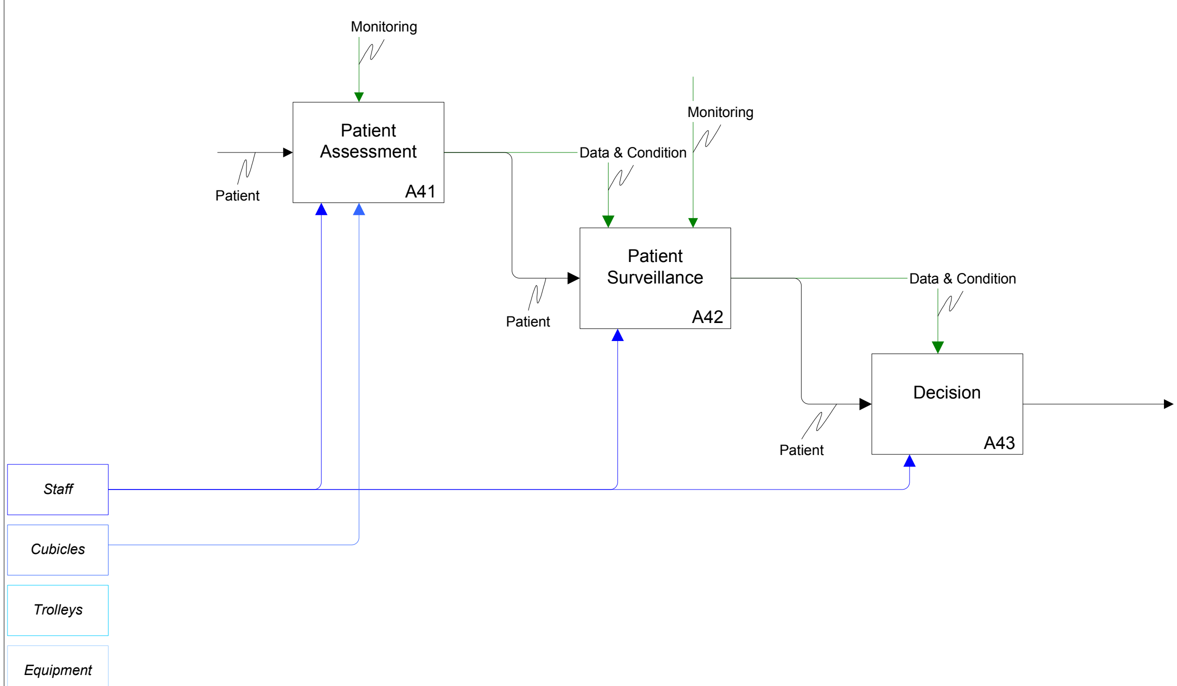

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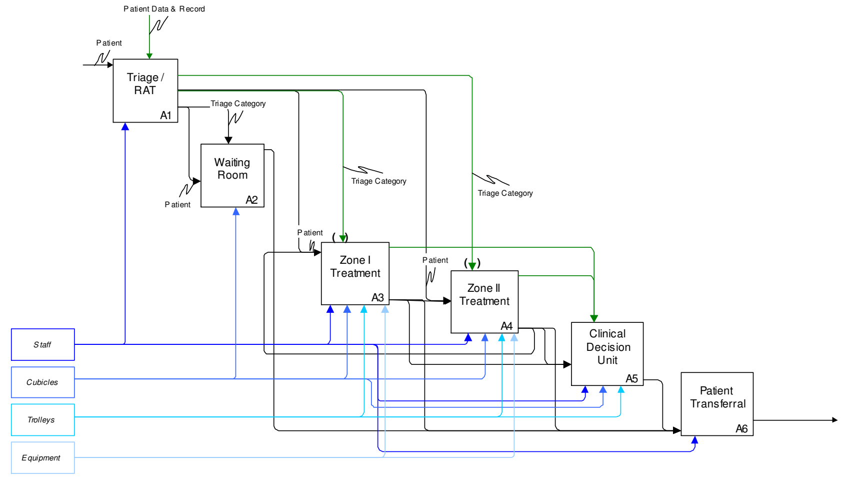
					RECOMMENDED			
	NOTES:				PUBLICATION			

Patient Transferal

Before any patient is ready to leave the ED, the patient record will be updated. The patient will either wait in his cubicle or moved to the corridor to free up a cubicle. Nurses usually look after the patient who are supposed to leave the hospital until they will be collected or driven home.



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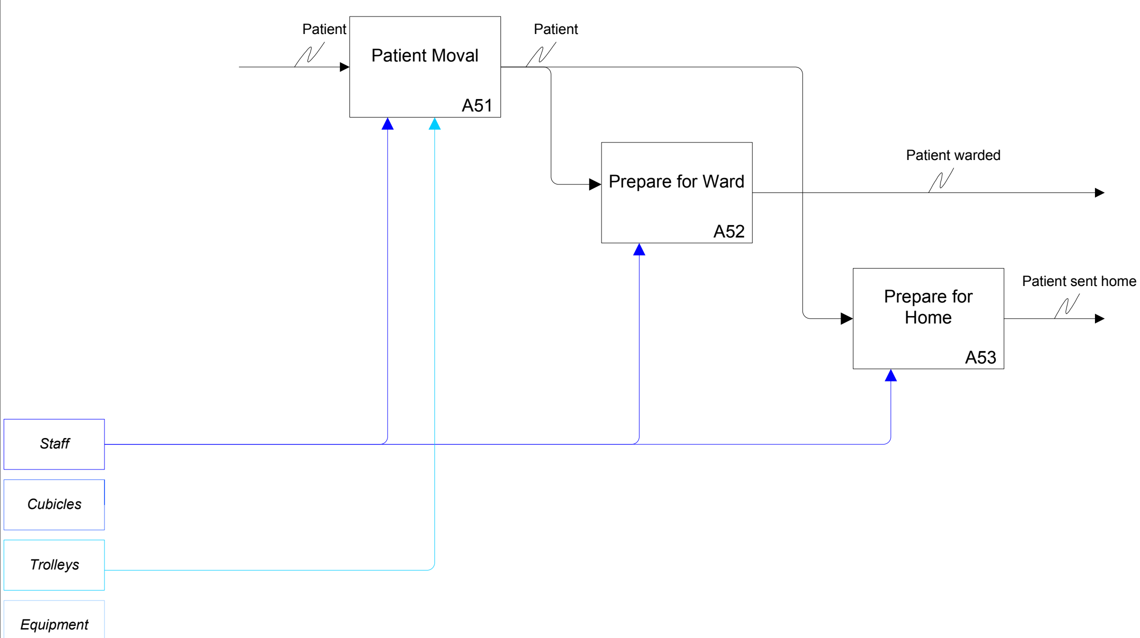

NODE:	A5	TITLE:	Patient Transferal A5	NO.: 5

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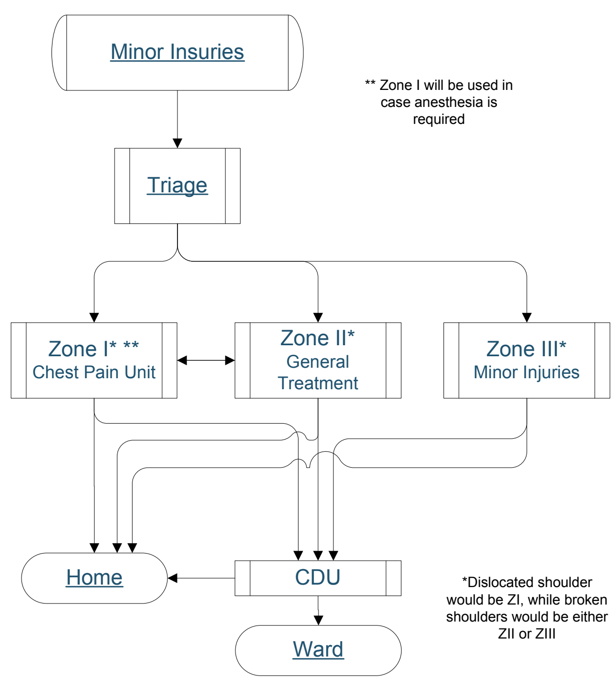
ED in SVUH	PROJECT: PM of ED@SVUH	REV.:	2.0		DRAFT			☐
					RECOMMENDED			
	NOTES:				PUBLICATION			

Minor Injuries

Minor injuries is a misleading terminology, because the treatment can get quite complicated (e.g. injuries to the hand, treatment with special pain killers in painful cases like a shoulder displacement).

Most common pathway for minor injuries: the patients are triaged and are sent to the Zone III for further treatment. Usually they get a X-Ray which is used for the diagnosis. Treatment is also applied in Zone III before they are sent home. The patients are either asked to come back in couple of weeks, or to be seen by their local GP.

Zone I or II is applied for example if painkillers are needed (e.g. shoulder displacement).



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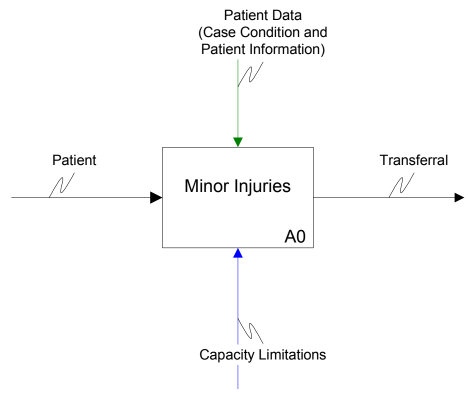

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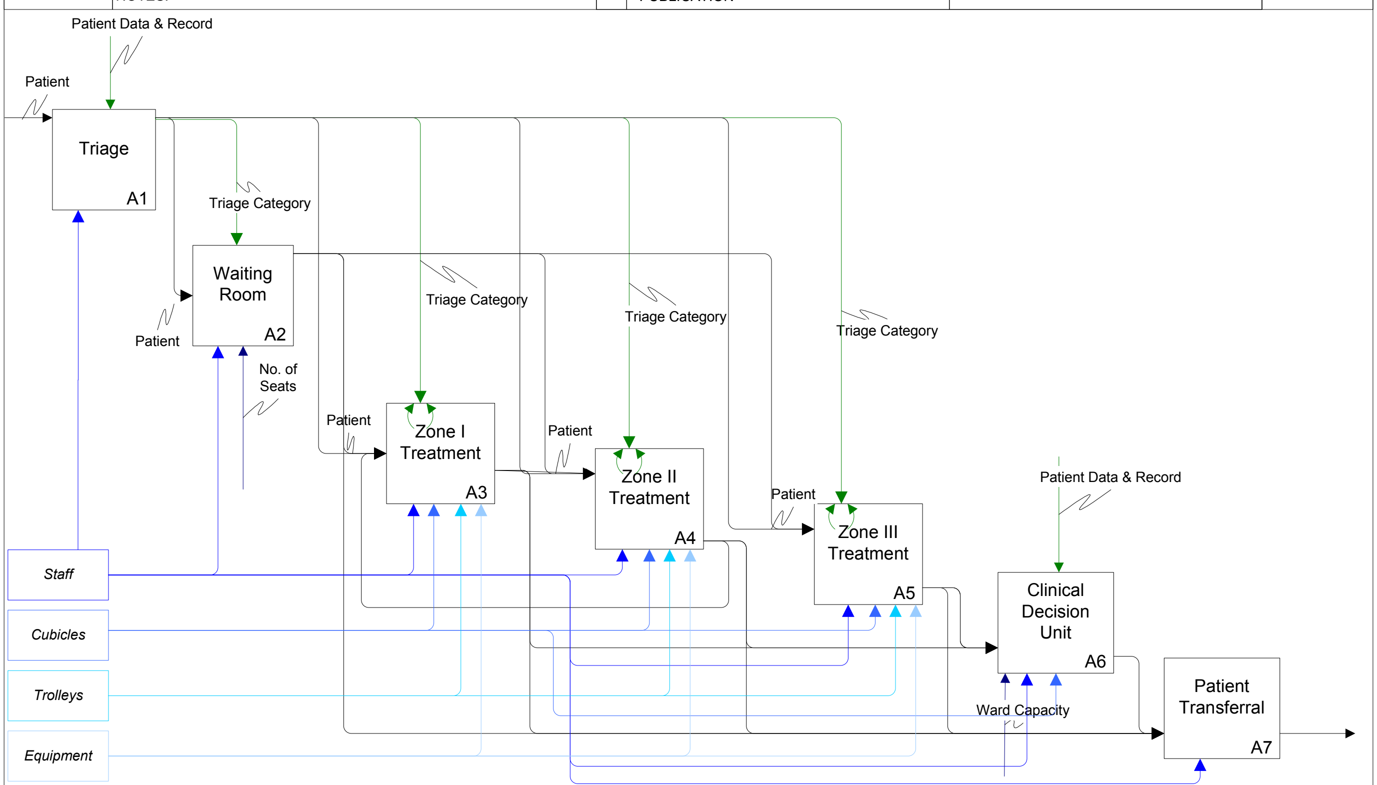

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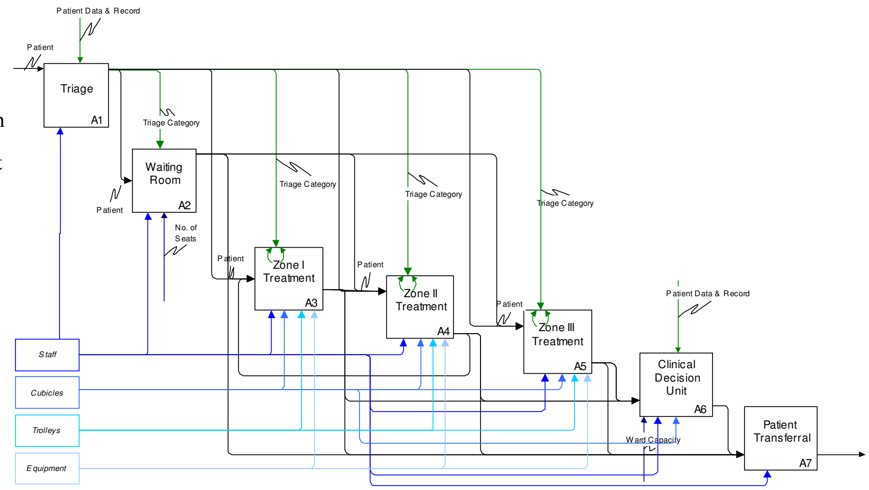
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Triage

The triage for patients with minor injuries is done by the triage team. The patient is assessed based on the accident and a patient record is made. The details obtained from the patient are then handed to the administrational staff. Blood samples are taken as soon as the patient is in a safe environment. The administrational staff is then arranging an appointment for X-Ray. All the findings and diagnostic results are stored in a patient record.



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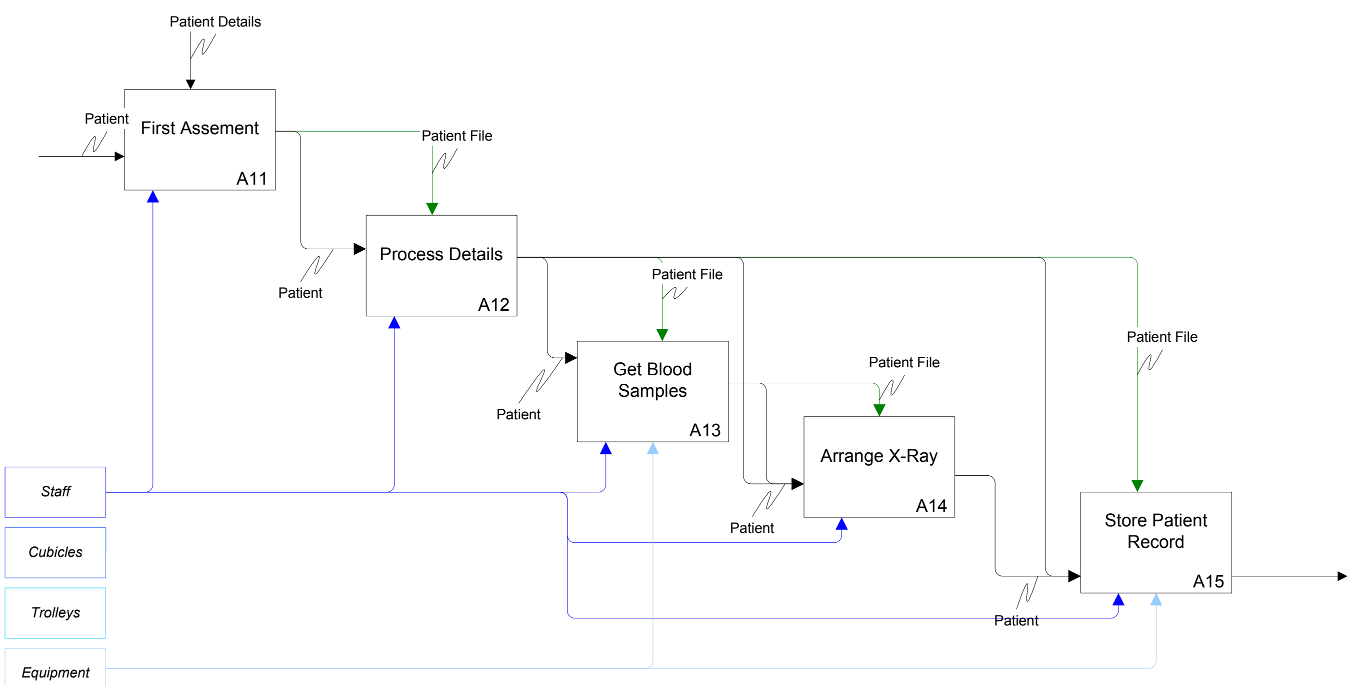

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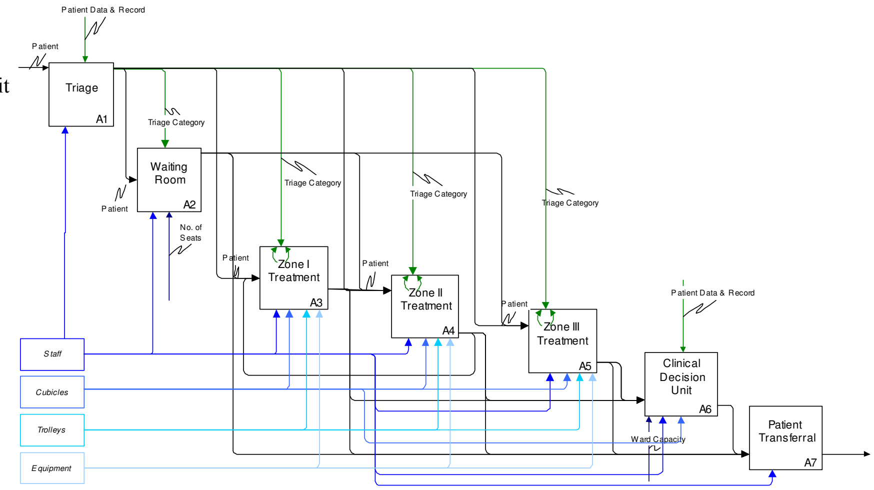
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Waiting Room

In low severe cases and full capacity of the ED the patient will be sent back to the waiting room. Patient waits for X-Ray. After X-Ray the patients have to wait in a preset location to discuss their cases.



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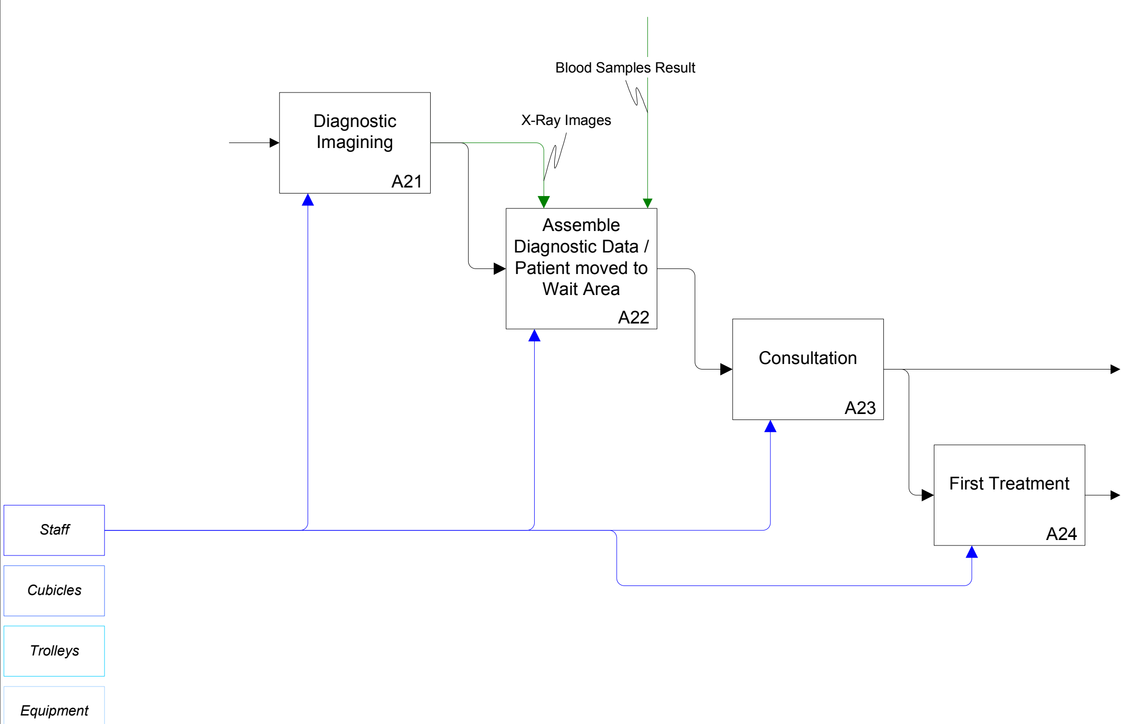

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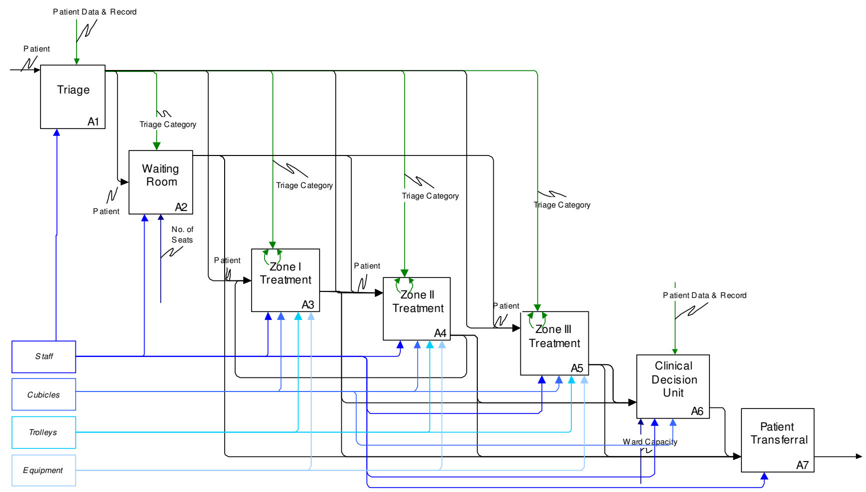
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone I

The basic procedures are similar to Zone II. Zone I is reserved for Chest Pain patients.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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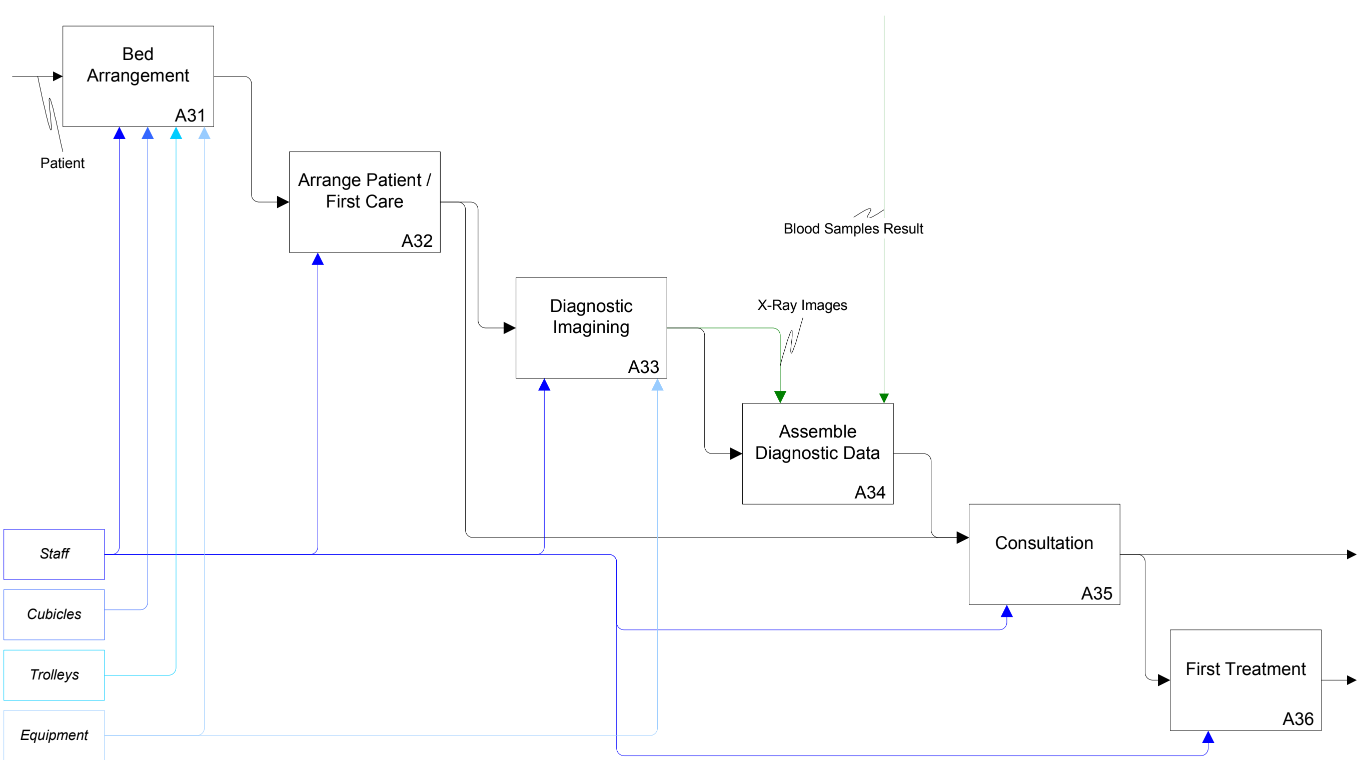

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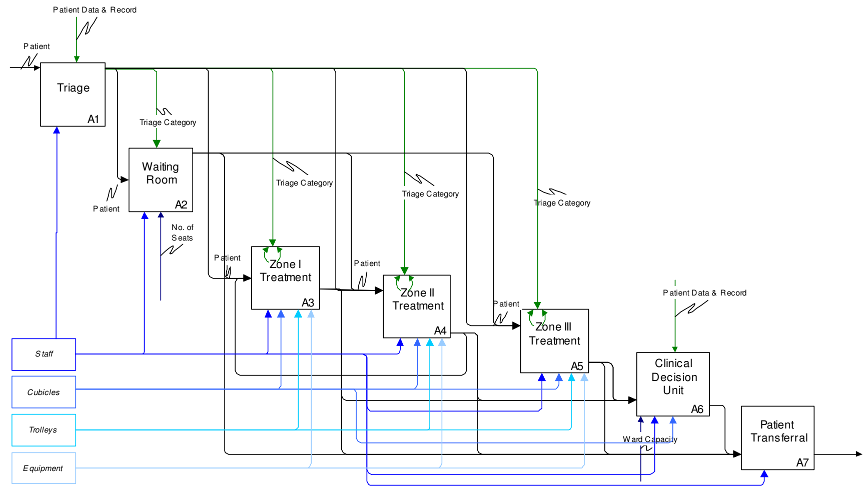
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone II

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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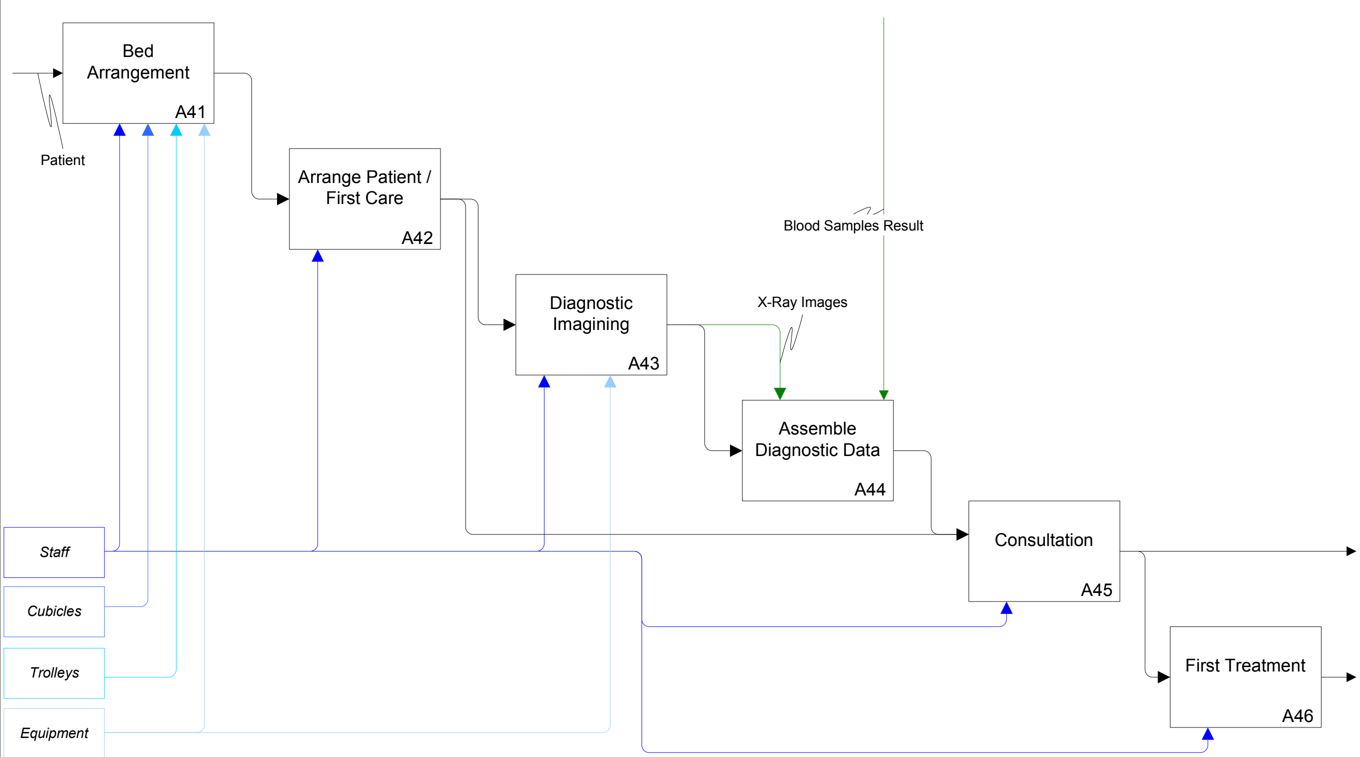

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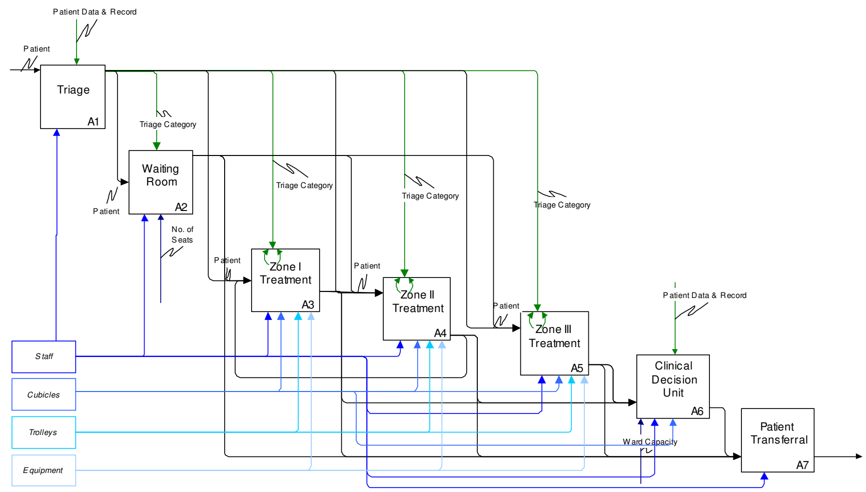
Zone III

Zone III is mainly used for patients of the 'Minor Injuries'.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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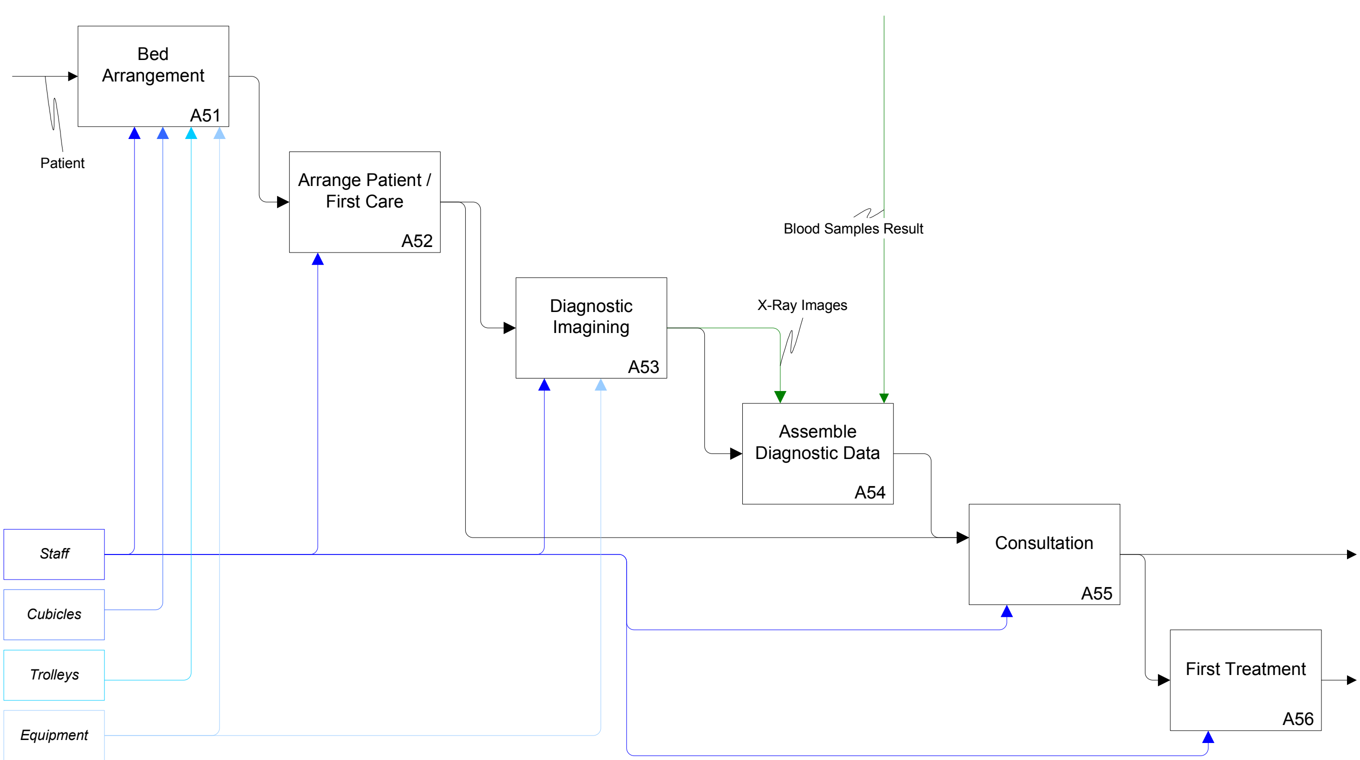

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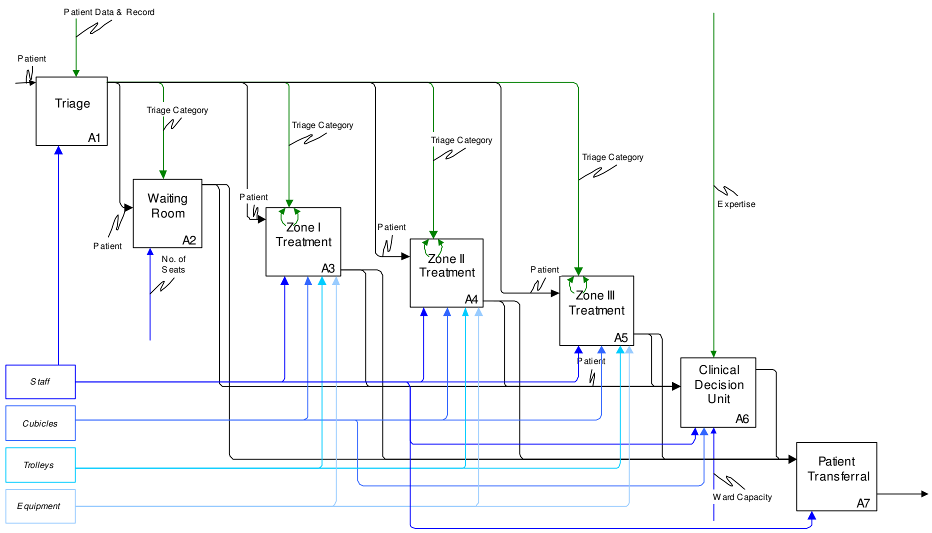
	NOTES:			PUBLICATION			

Clinical Decision Unit

The Clinical Decision Unit (CDU) where the final decision is made whether to hospitalize the patients or sent them home. The decision is subject to patient condition and results from a considerable monitoring for the case status.



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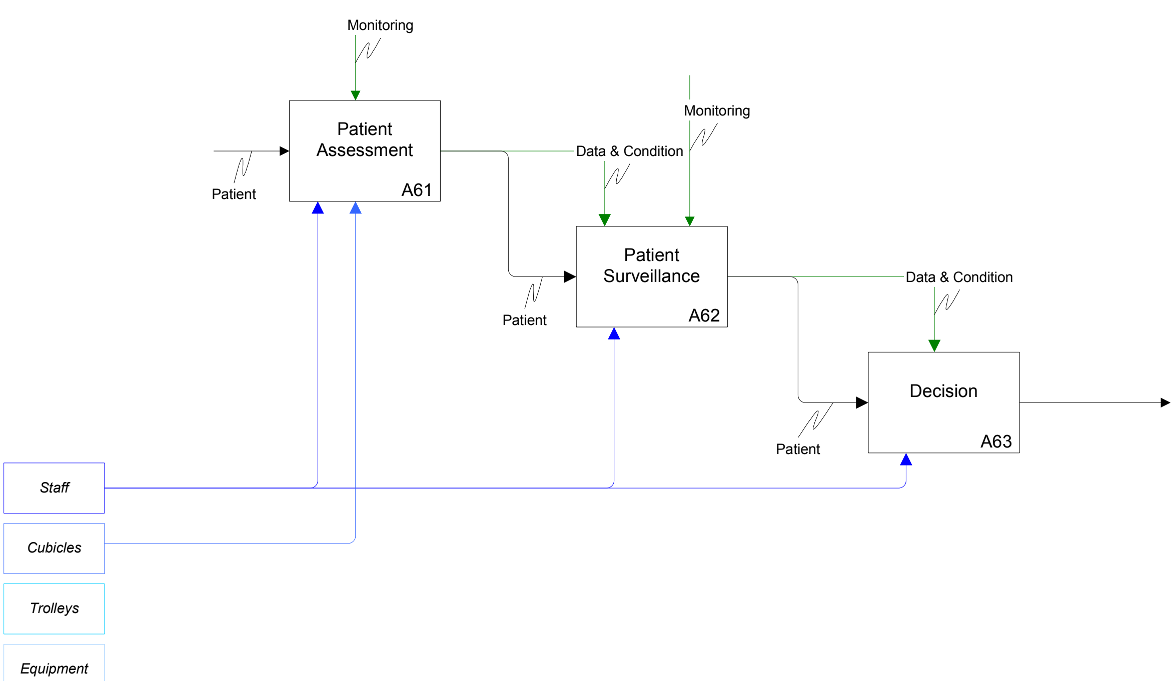

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ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
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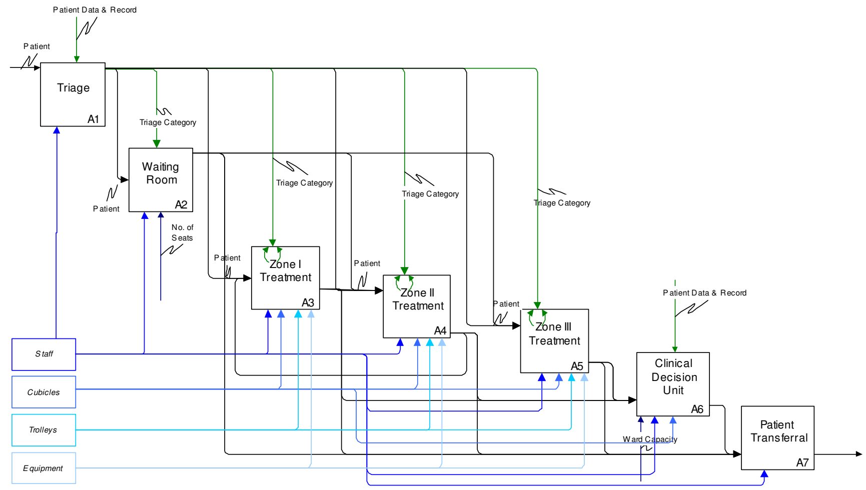
	NOTES:			PUBLICATION			

Patient Transferal

Before any patient is ready to leave the ED, the patient record will be updated. The patient will either wait in his cubicle or moved to the corridor to free up a cubicle. Nurses usually look after the patient who are supposed to leave the hospital until they will be collected or driven home.



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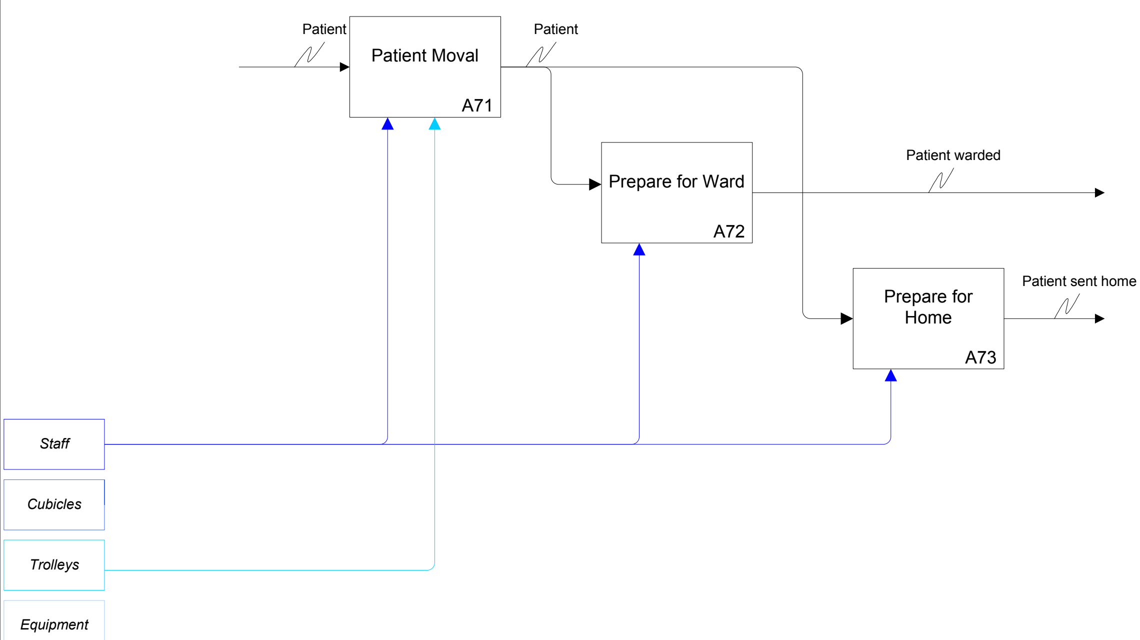

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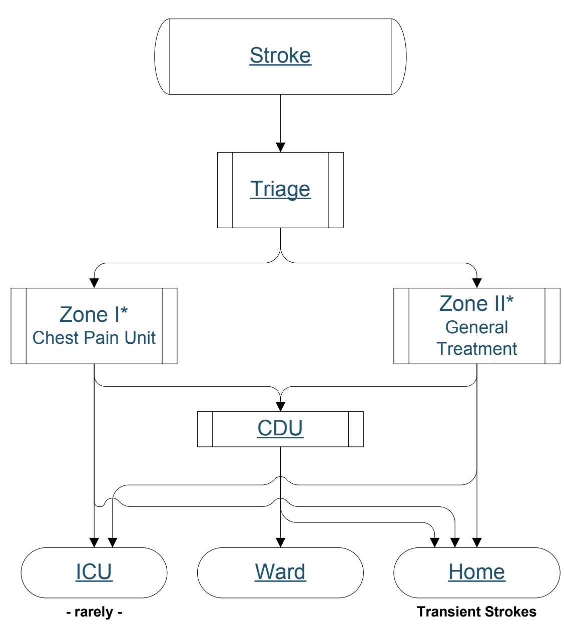
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			☐
				RECOMMENDED			
	NOTES:			PUBLICATION			

Patients with stroke

Patients with stroke suffer of many symptoms simultaneously. The first treatment should stabilise the patient. The range of the side effects is very high. Transient strokes (minor strokes, where the patient may experiencing dumbness) are quite common. Many patient with a transient stroke are in a stable condition and can be sent home. Usually stroke patients are warded. The patients are transferred to the ICU when an organ failure is likely.



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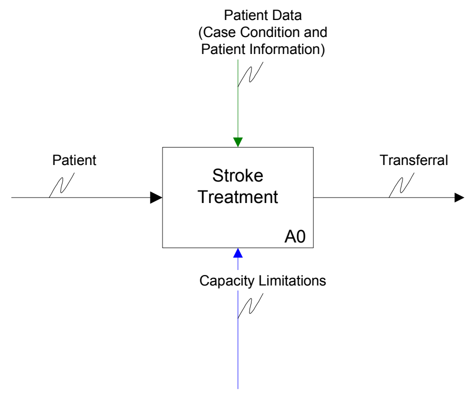

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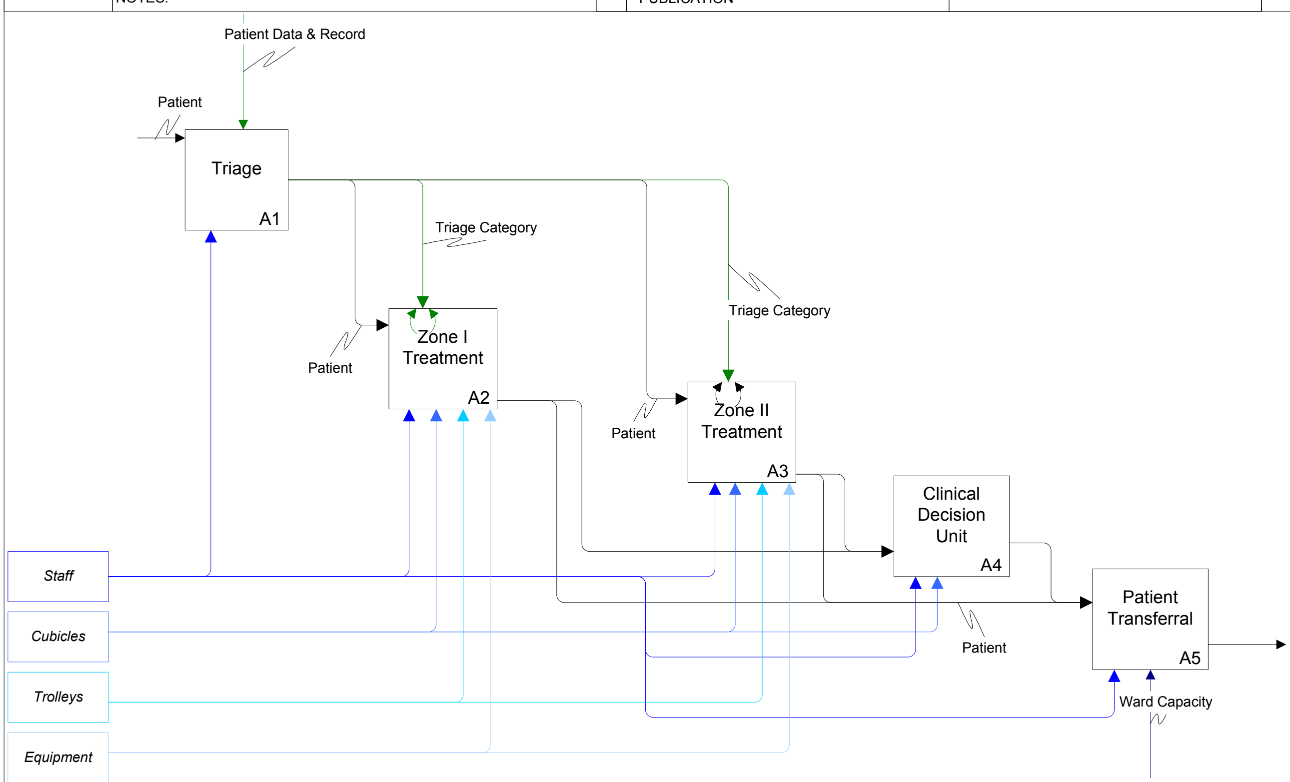

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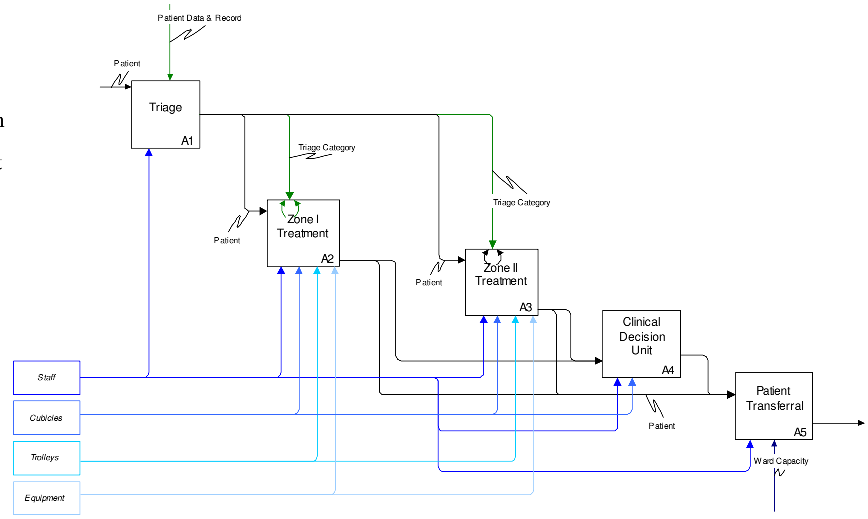
	NOTES:			PUBLICATION			

Triage

In cases of stroke the patient is triaged within the ambulance. The patient is assessed based on the accident and a patient record is made. The details obtained from the patient are then handed to the administrational staff. Blood samples are taken as soon as the patient is in a safe environment. The administrational staff is then arranging an appointment for X-Ray. All the findings and diagnostic results are stored in a patient record.



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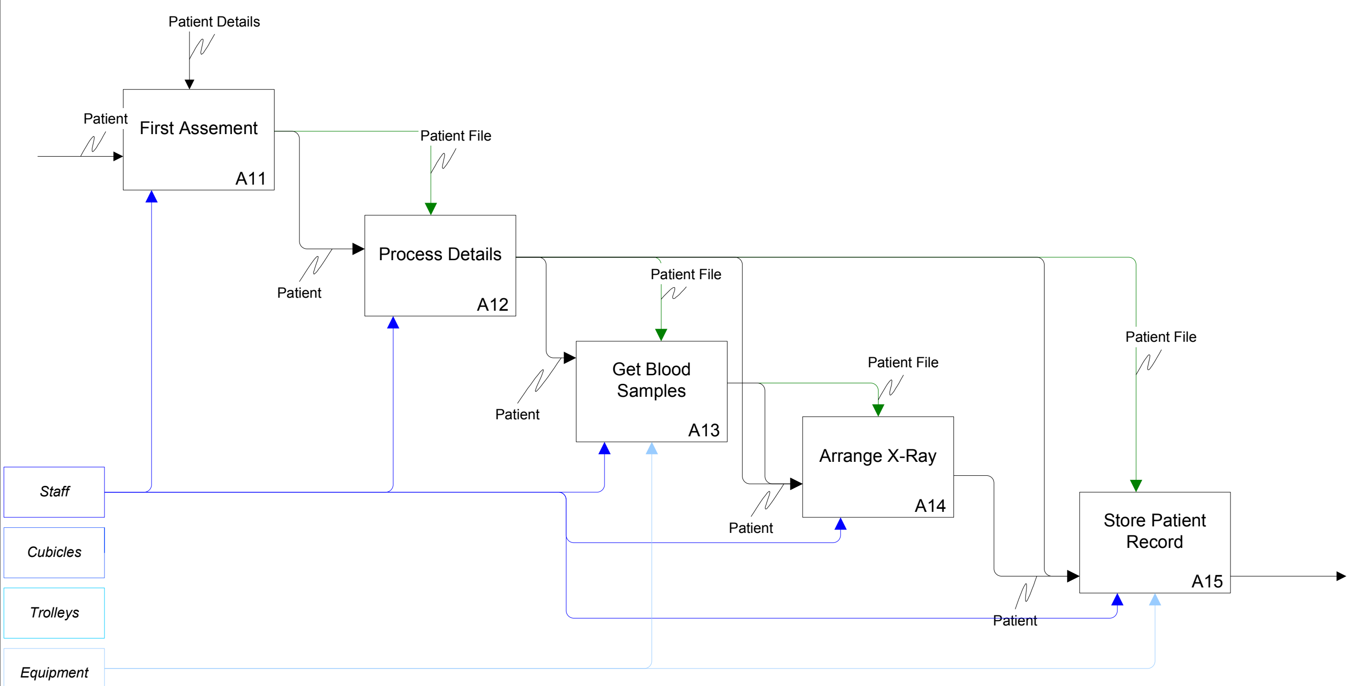

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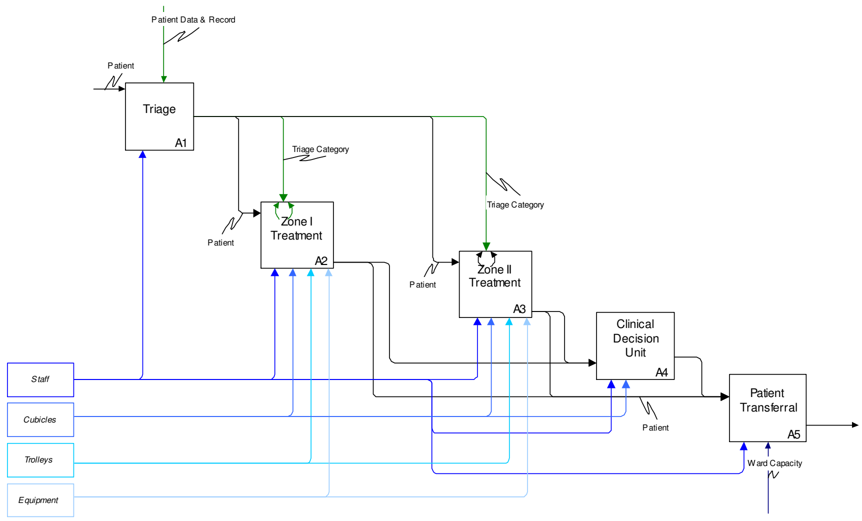
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone I

The basic procedures are similar to Zone II. Zone I is reserved for Chest Pain patients, but in cases of overcrowding of Zone II and Zone I might be used for stroke patients.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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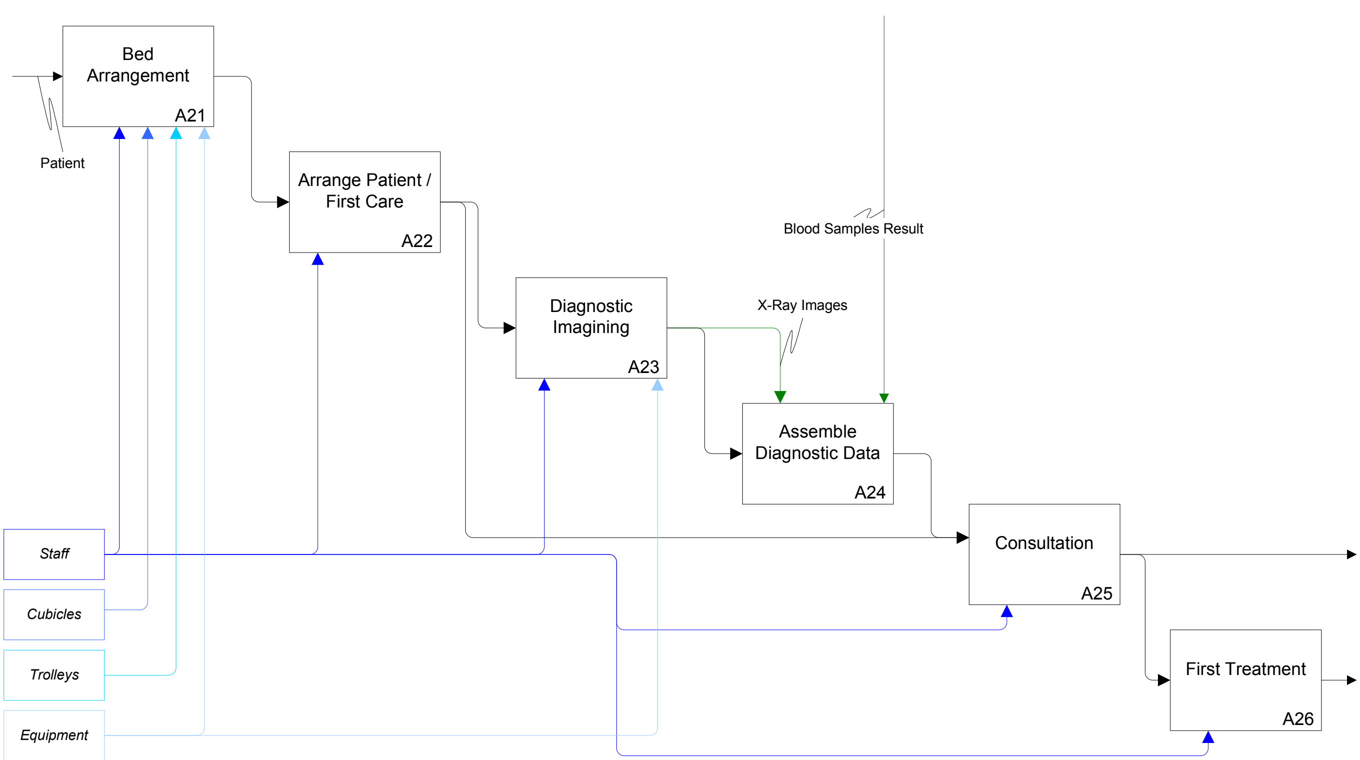

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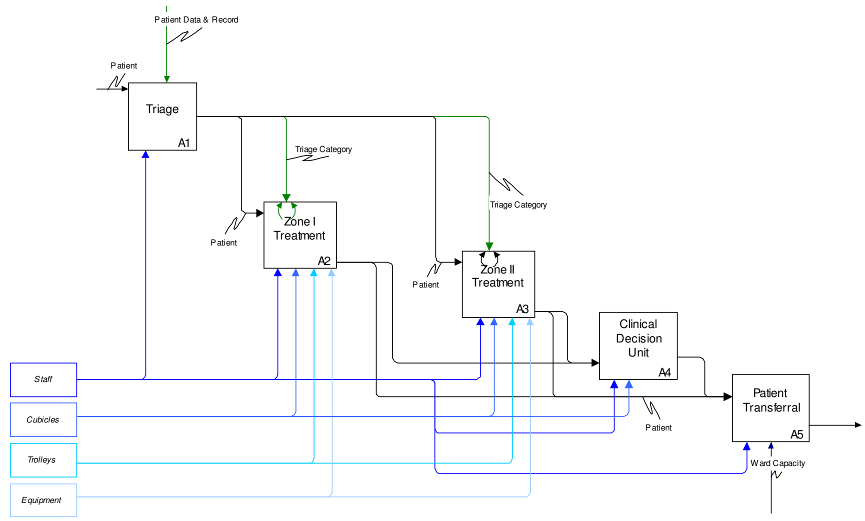
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone II

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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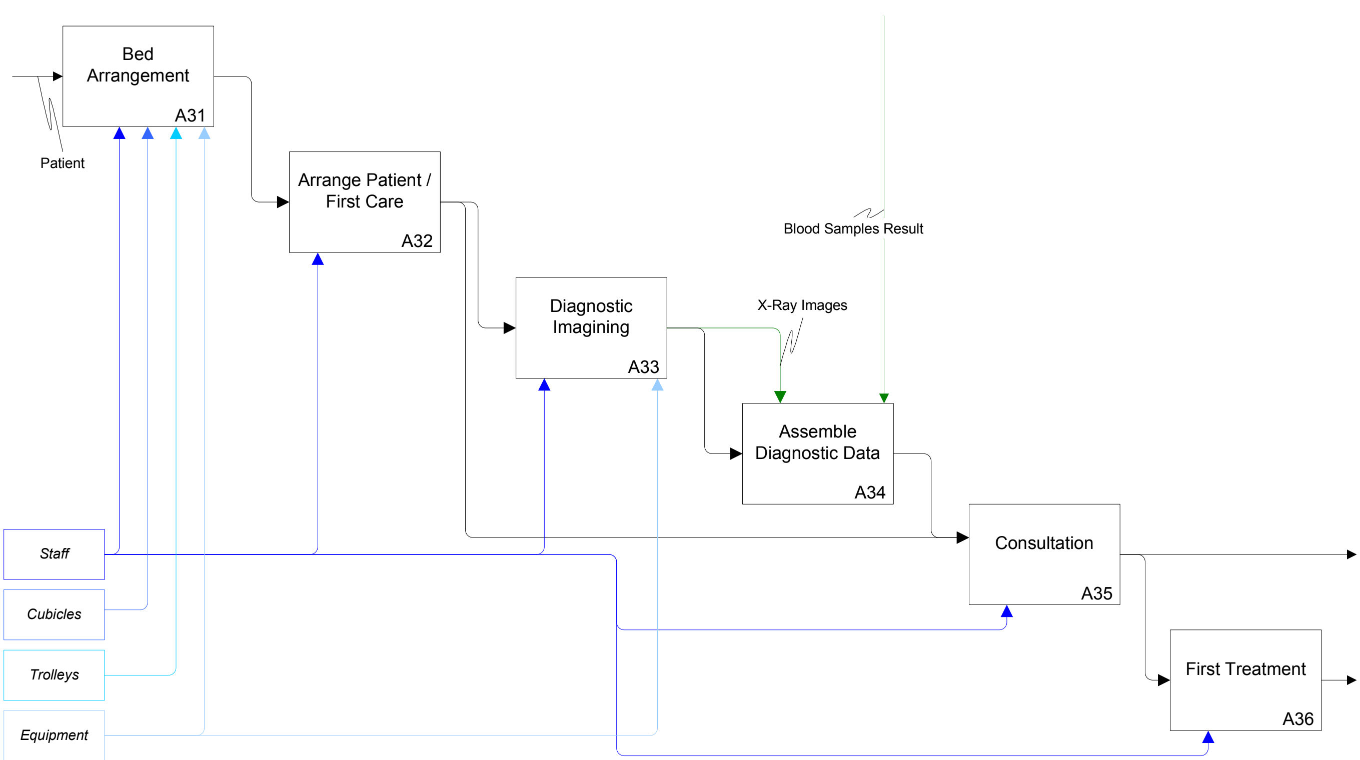

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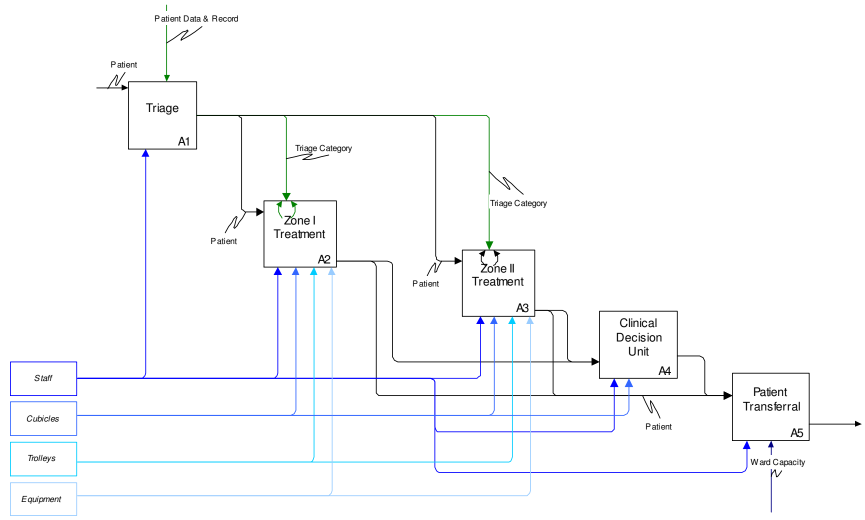
Clinical Decision Unit

The Clinical Decision Unit (CDU) where the final decision is made whether to hospitalize the patients or sent them home. The decision is subject to patient condition and results from a considerable monitoring for the case status.



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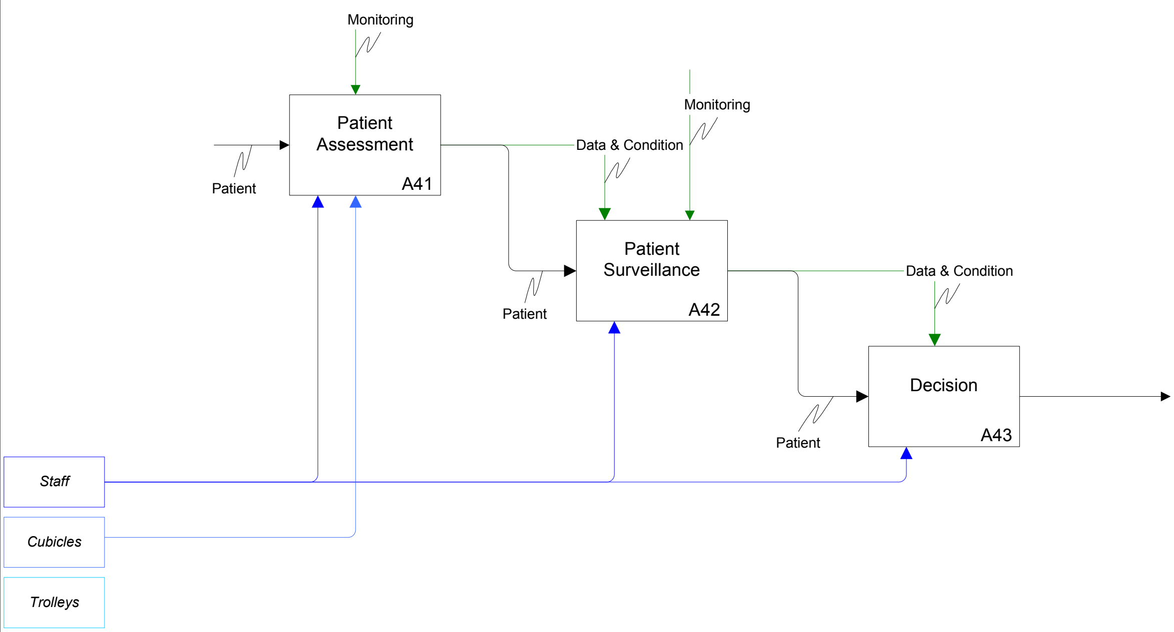

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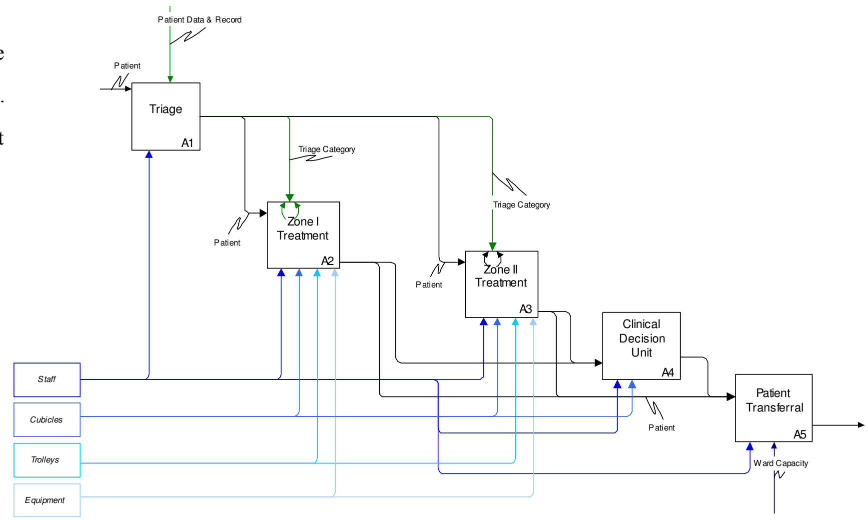
				RECOMMENDED			
	NOTES:			PUBLICATION			

Patient Transferral

In case that the patient is still in a severe condition, the patient will be transferred to the ICU immediately. Otherwise he will be assessed on his current condition.

Before any patient is ready to leave the ED, the patient record will be updated. The patient will either wait in his cubicle or moved to the corridor to free up a cubicle. Nurses usually look after the patient who are supposed to leave the hospital until they will be collected or driven home.



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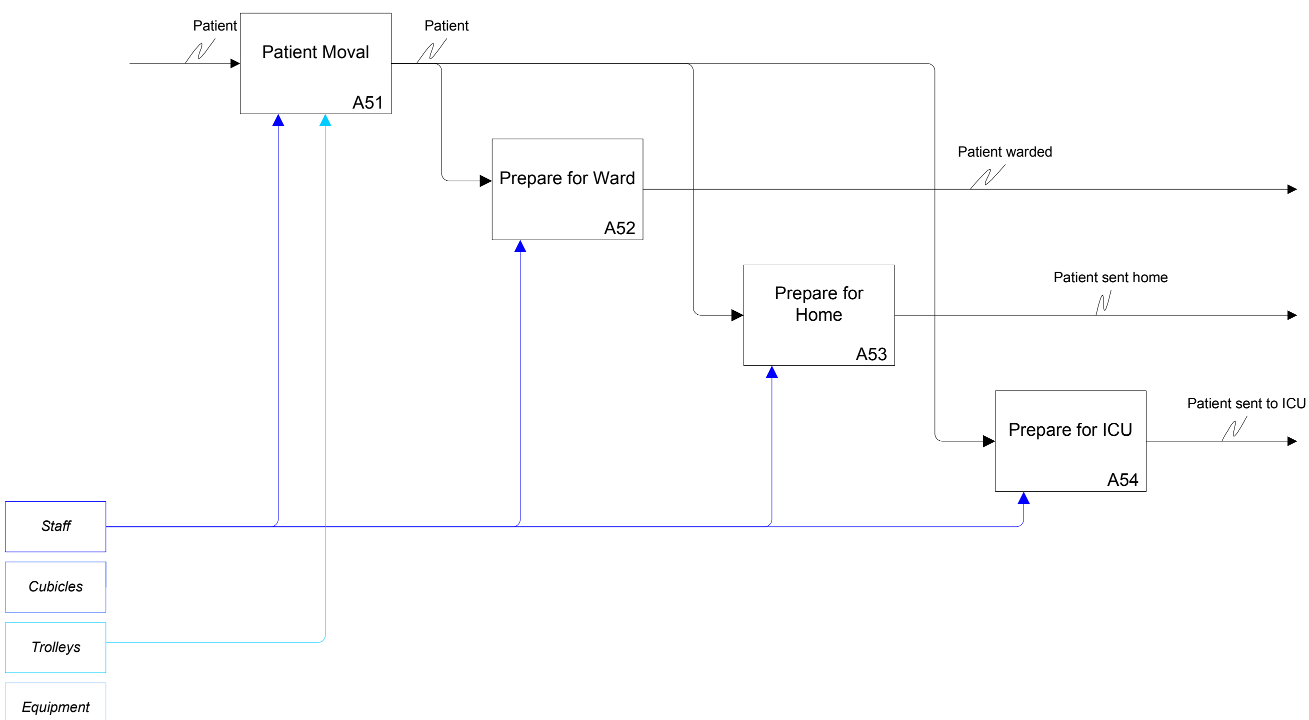

NODE: A5	TITLE: Patient Transferal A5	NO.: 7

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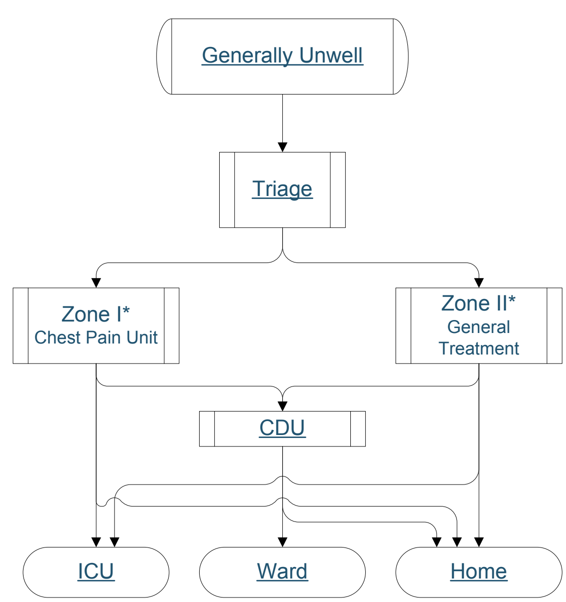
				RECOMMENDED			
	NOTES:			PUBLICATION			

<u>Treatment of Generally Unwell patients</u>

Patients that are sick and not feeling well are getting fully assessed and diagnosed in order to determine the source of their sickness. Patients that are generally unwell are triaged and are then assessed and consulted in the Zone I or II.
Depending on the diagnosis the patients are either sent home, to the ICU or are warded.



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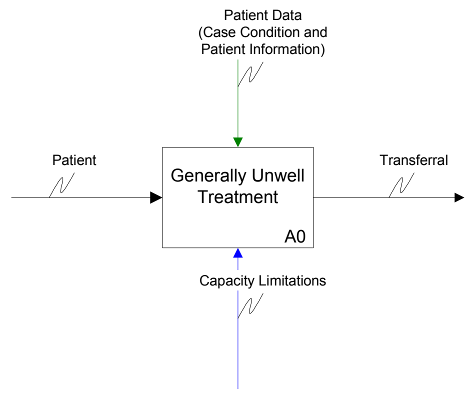

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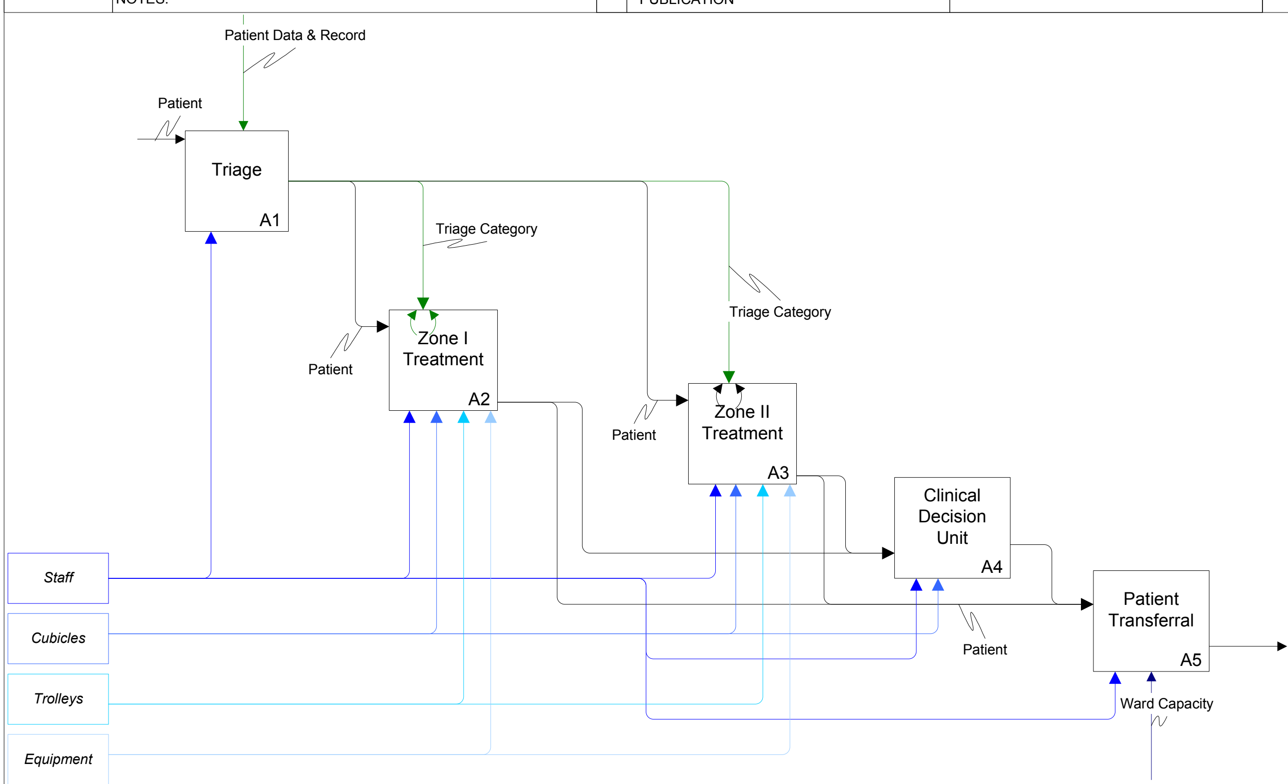

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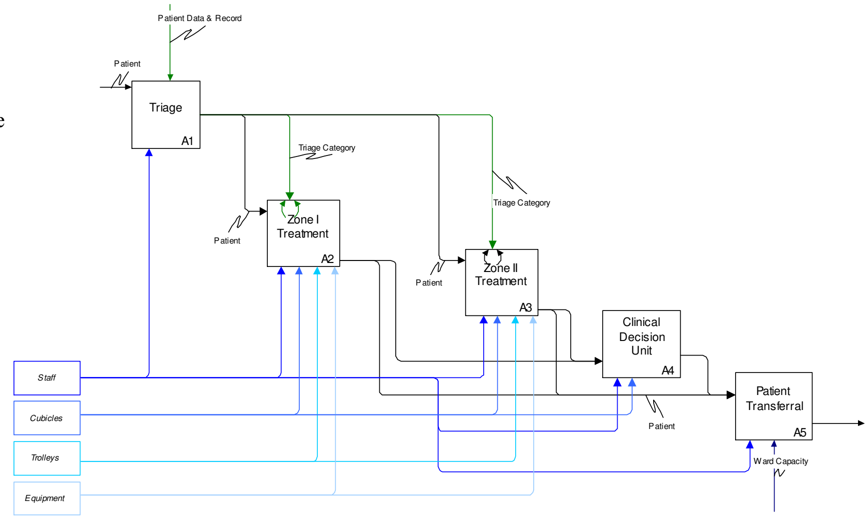
	NOTES:			PUBLICATION			

Triage

The triage procedure for patients who are generally feeling unwell is done by the triage team. The patient is assessed based on the accident and a patient record is made. The details obtained from the patient are then handed to the administrational staff. Blood samples are taken as soon as the patient is in a safe environment. The administrational staff is then arranging an appointment for X-Ray. All the findings and diagnostic results are stored in a patient record.



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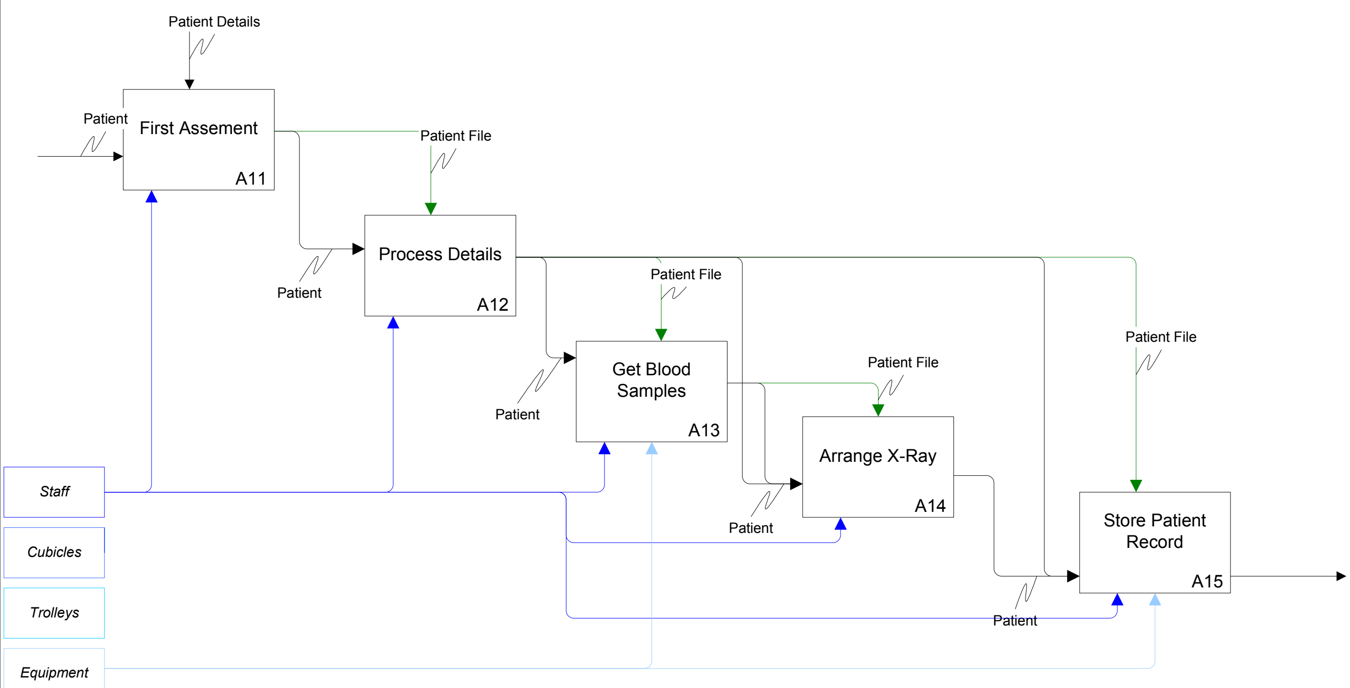

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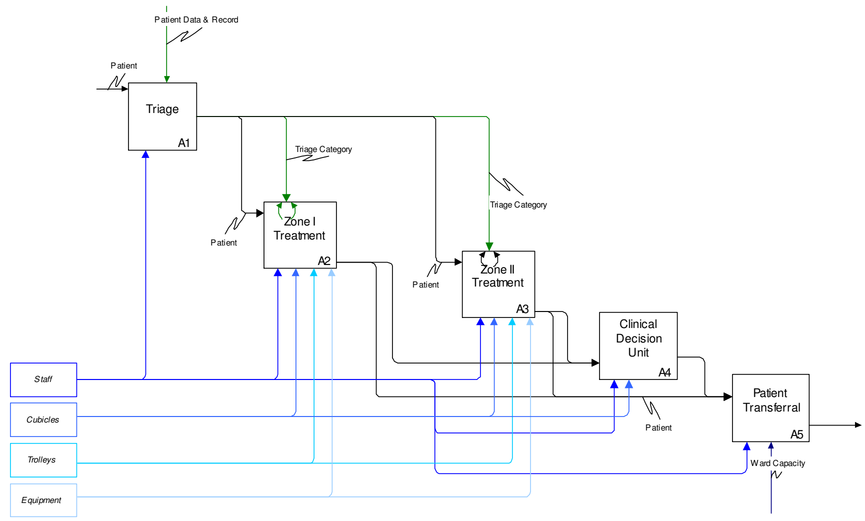
					RECOMMENDED			
	NOTES:				PUBLICATION			

Zone I

The basic procedures are similar to Zone II. Zone I is reserved for Chest Pain patients, but in cases of overcrowding of Zone II and Zone I might be used for generally unwell patients.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.

As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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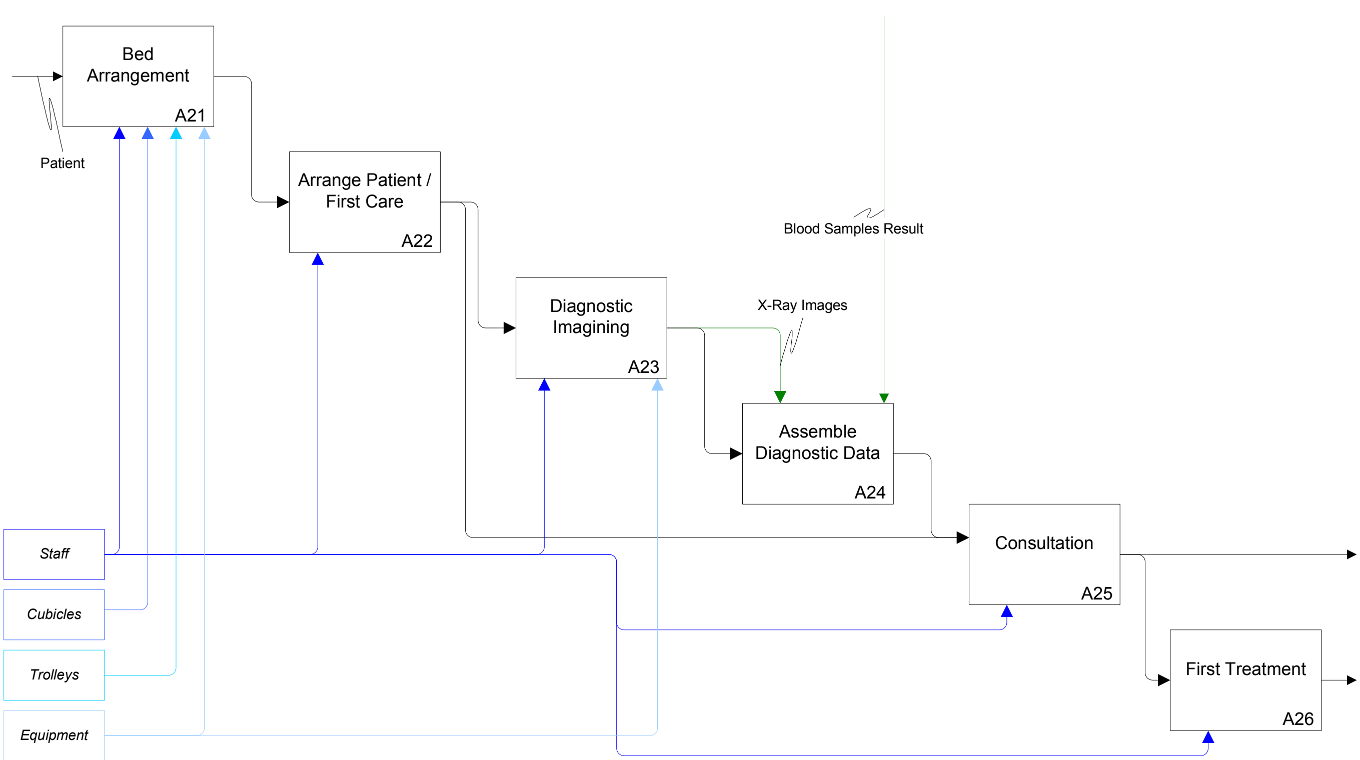

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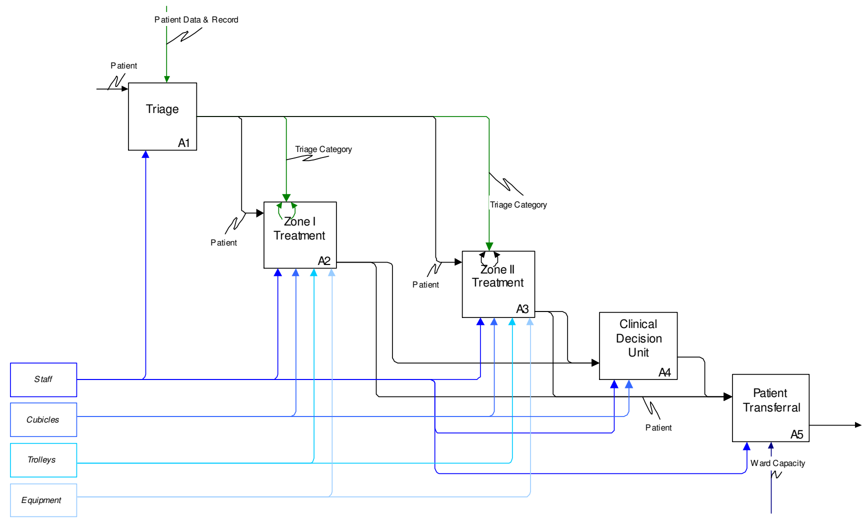
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone II

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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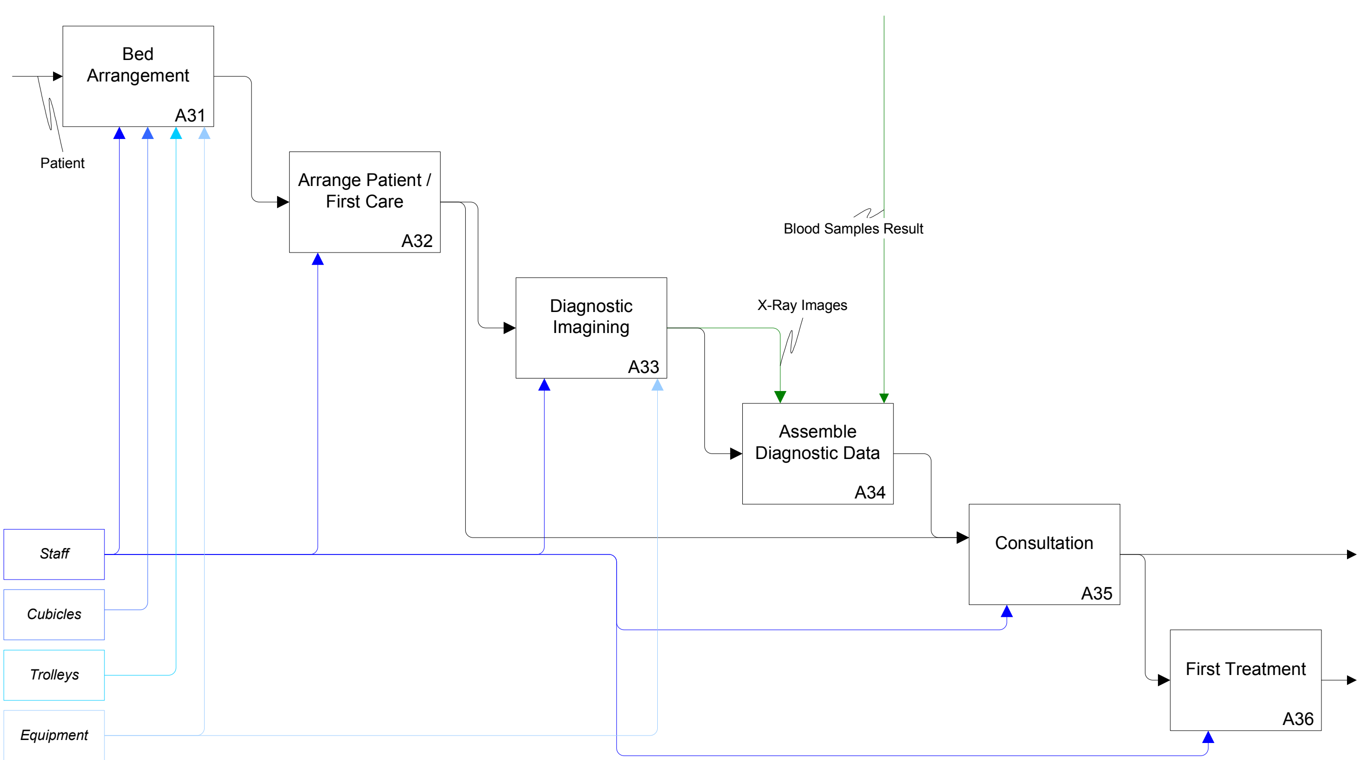

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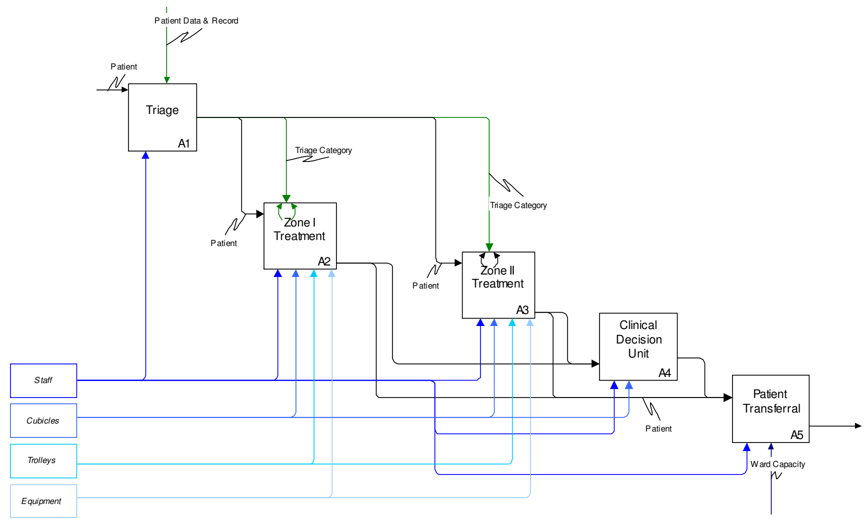
				RECOMMENDED			
	NOTES:			PUBLICATION			

Clinical Decision Unit

The Clinical Decision Unit (CDU) where the final decision is made whether to hospitalize the patients or sent them home. The decision is subject to patient condition and results from a considerable monitoring for the case status.



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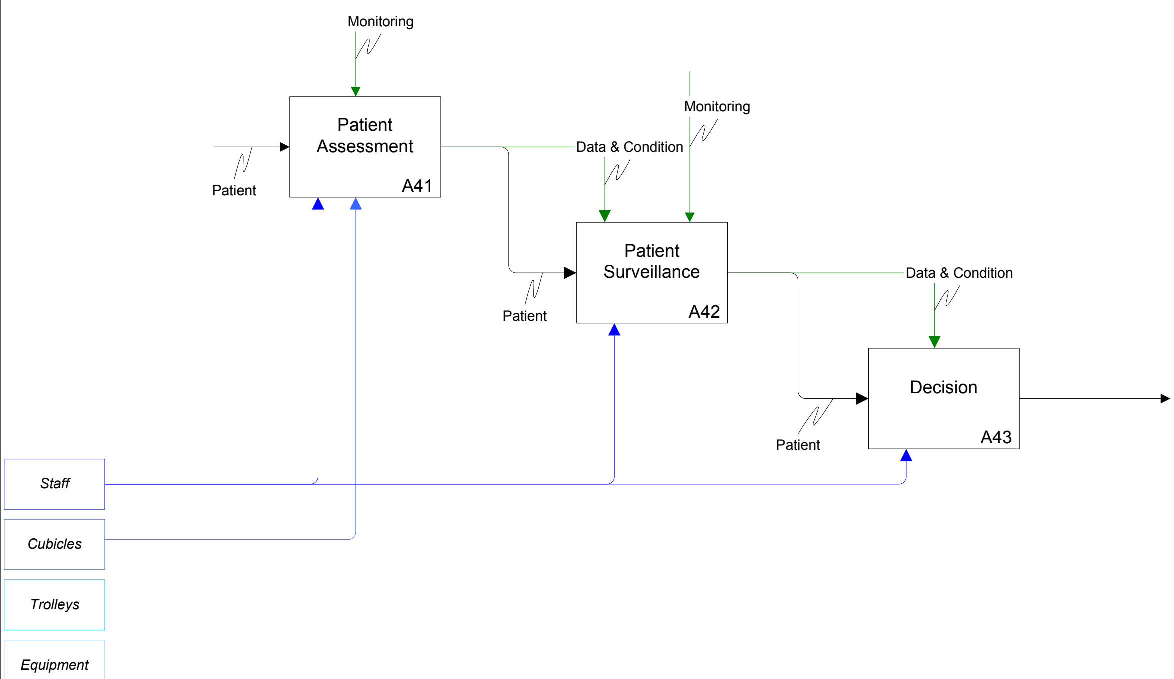

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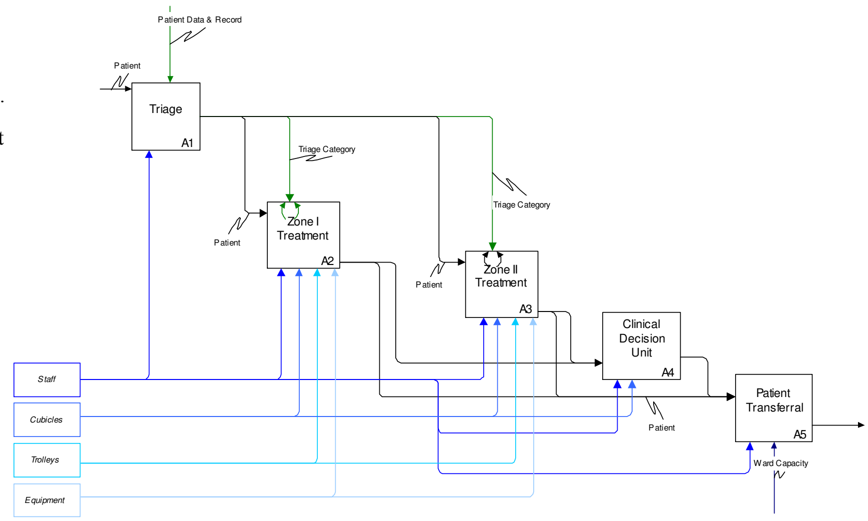
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Patient Transferral

In case that the patient is in a severe condition, the patient will be transferred to the ICU immediately. Otherwise he will be assessed on his current condition.

Before any patient is ready to leave the ED, the patient record will be updated. The patient will either wait in his cubicle or moved to the corridor to free up a cubicle. Nurses usually look after the patient who are supposed to leave the hospital until they will be collected or driven home.



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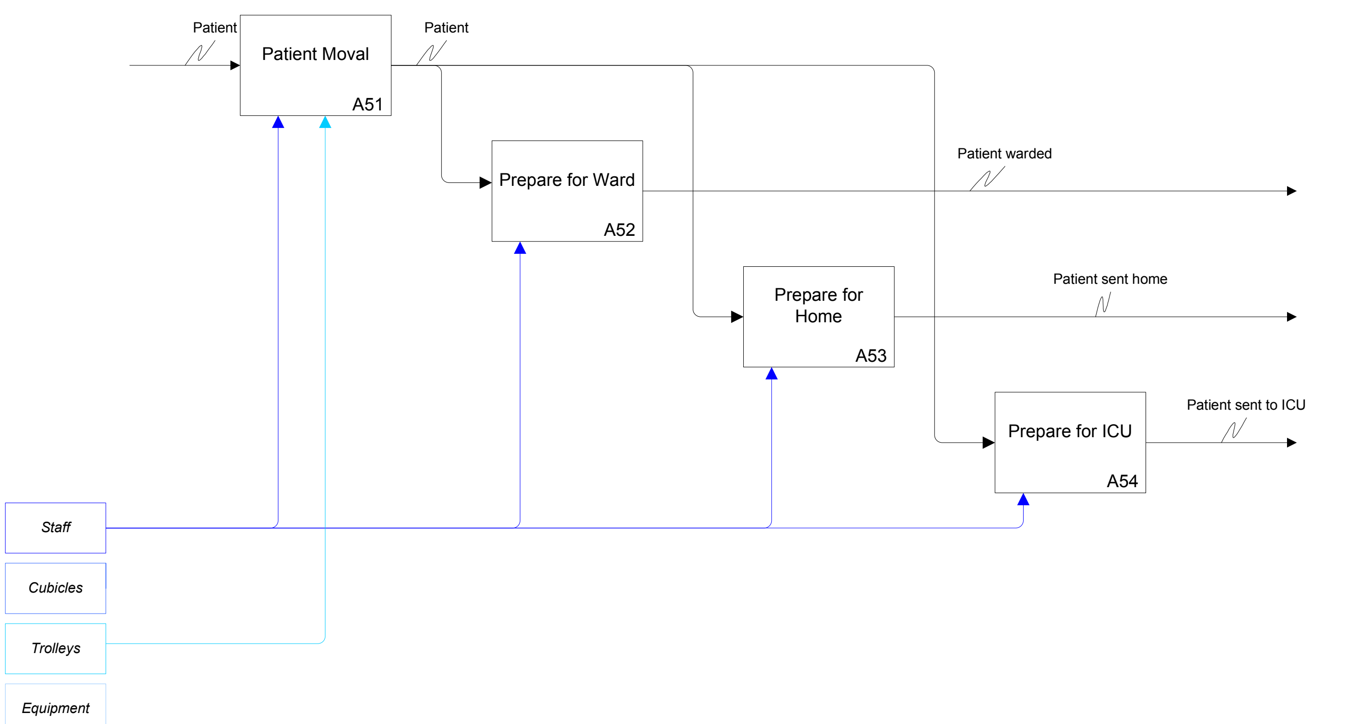

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ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
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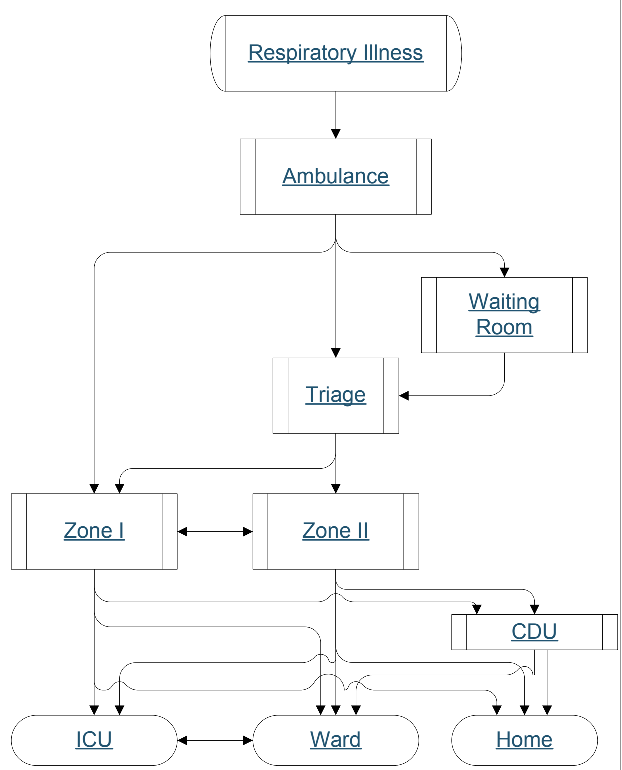
	NOTES:			PUBLICATION			

Treatment for Respiratory Illnesses

Respiratory illnesses are triaged in a high category level. The patients are in a severe condition and need immediate treatment and monitoring. Commonly these patients arrive via ambulance and are sent directly to Zone I for monitoring, first assessment and treatment. In lower severe cases the patients are triaged or even placed in the waiting room (rarely). After assessing the patient in triage it will be decided where the patient will be placed.
Depending on the category level and the severity the patient will be either transferred to the ICU or the ward or sent home if the condition of the patient is considered to be safe.



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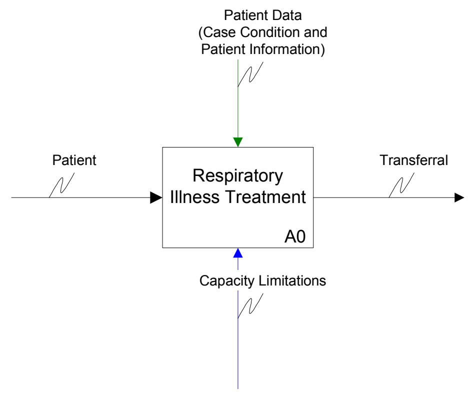

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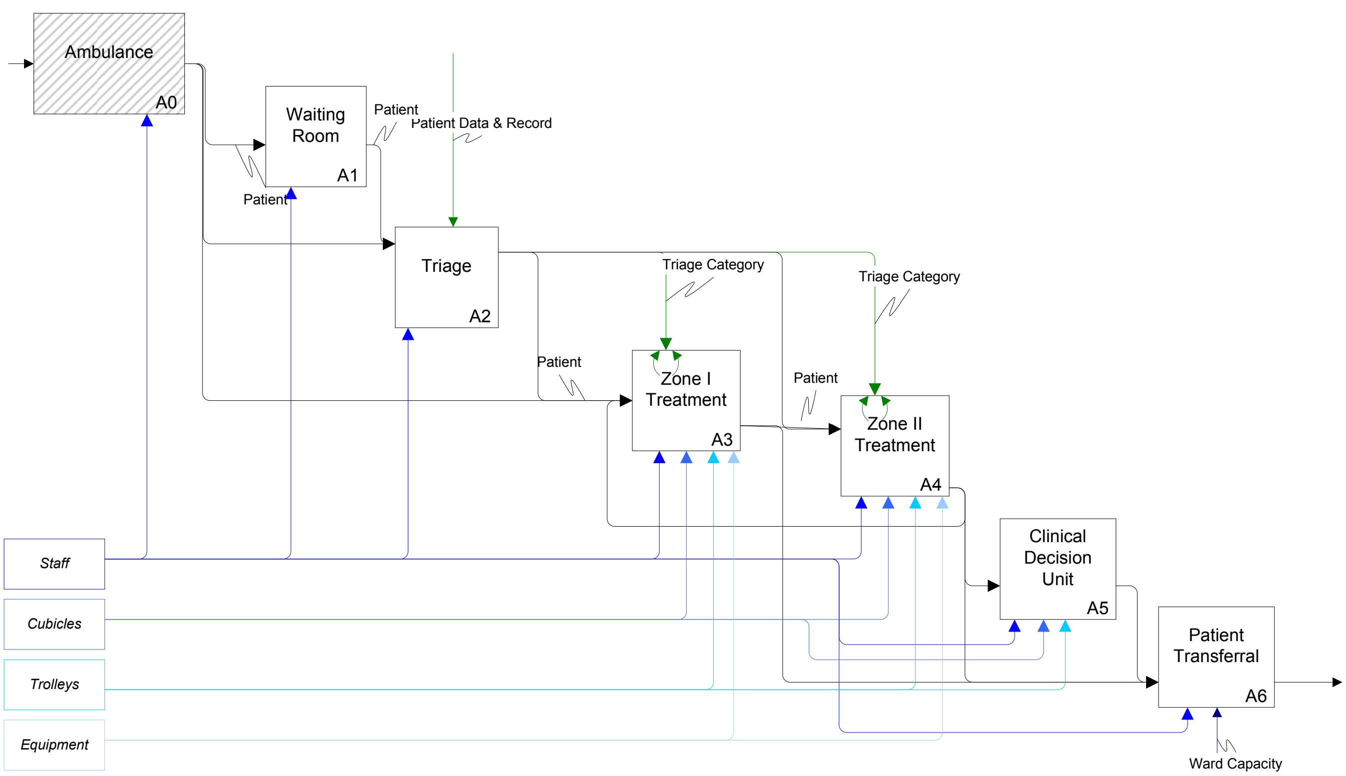

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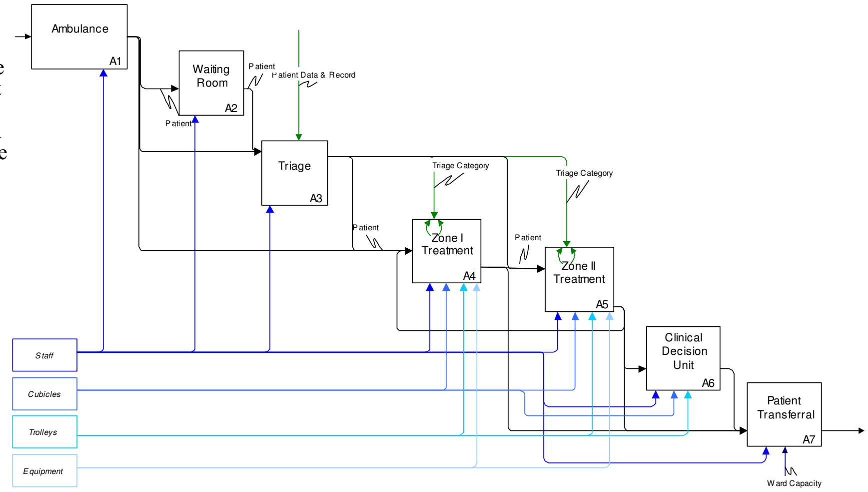
	NOTES:			PUBLICATION			

Triage

The triage procedure for patients with respiratory illnesses is done by the triage team. In severe cases the patients are usually sent straight to Zone I. The patient is assessed based on the accident and a patient record is made. The details obtained from the patient are then handed to the administrational staff. Blood samples are taken as soon as the patient is in a safe environment. The administrational staff is then arranging an appointment for X-Ray. All the findings and diagnostic results are stored in a patient record.



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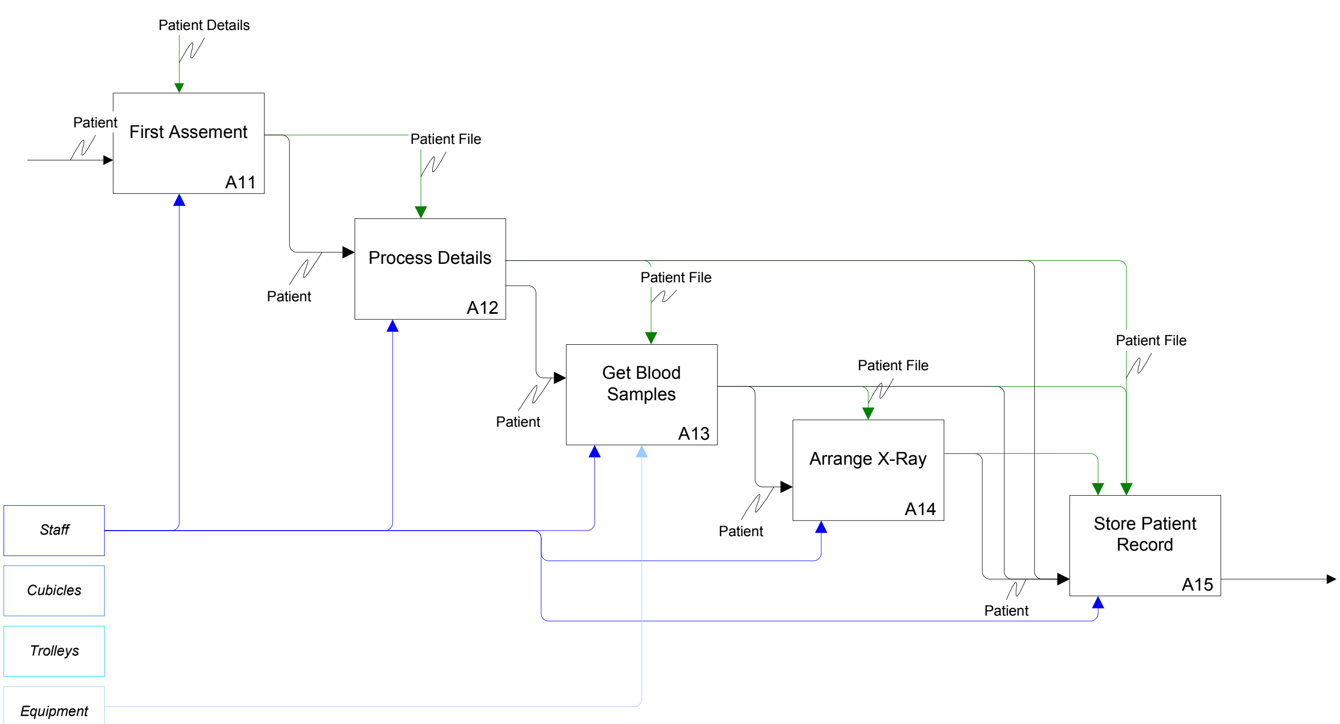

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ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
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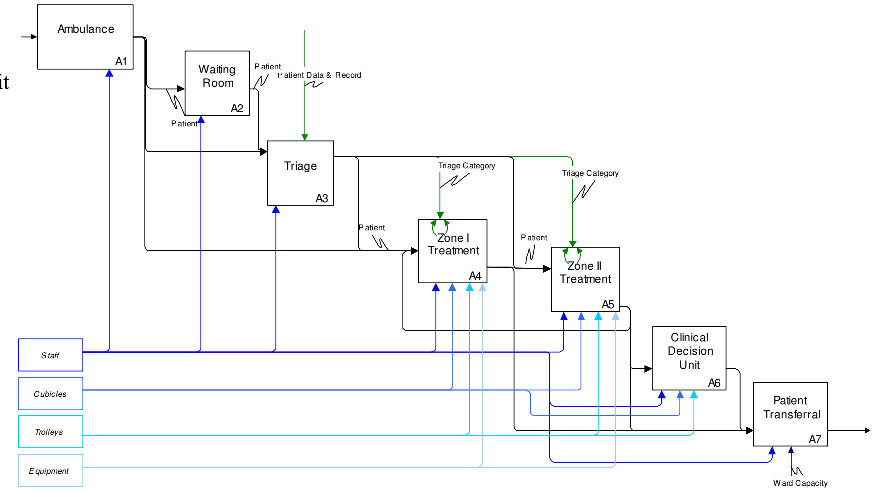
	NOTES:			PUBLICATION			

Waiting Room

In low severe cases and full capacity of the ED the patient will be sent back to the waiting room. Patient waits for X-Ray. After X-Ray the patients have to wait in a preset location to discuss their cases.



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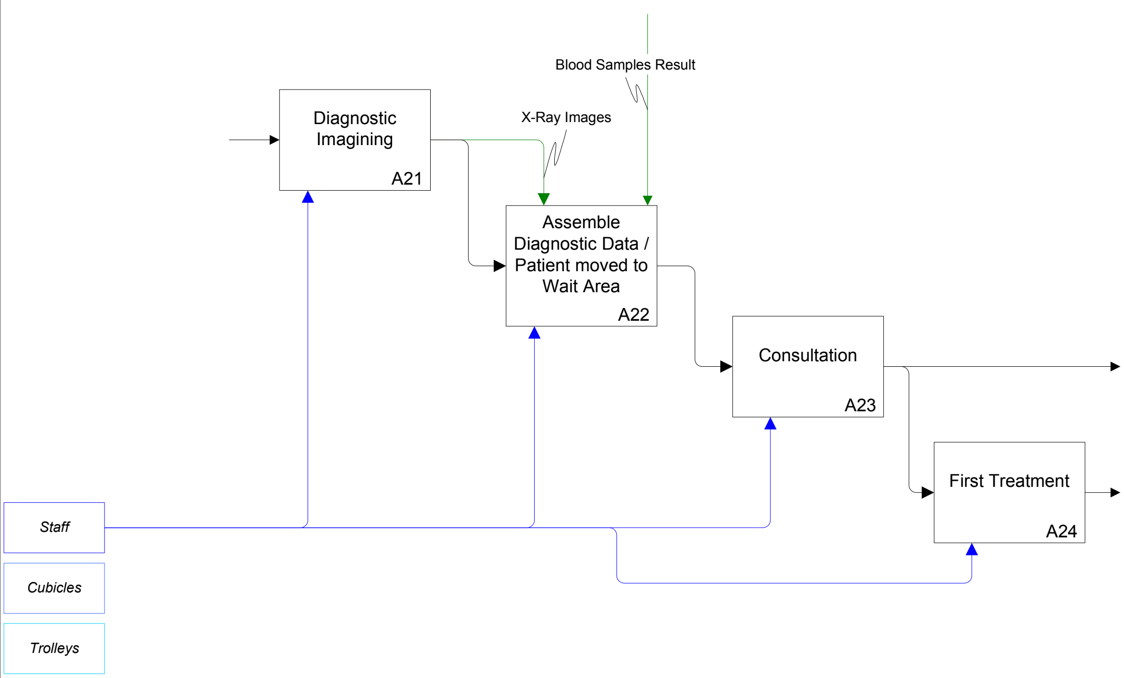

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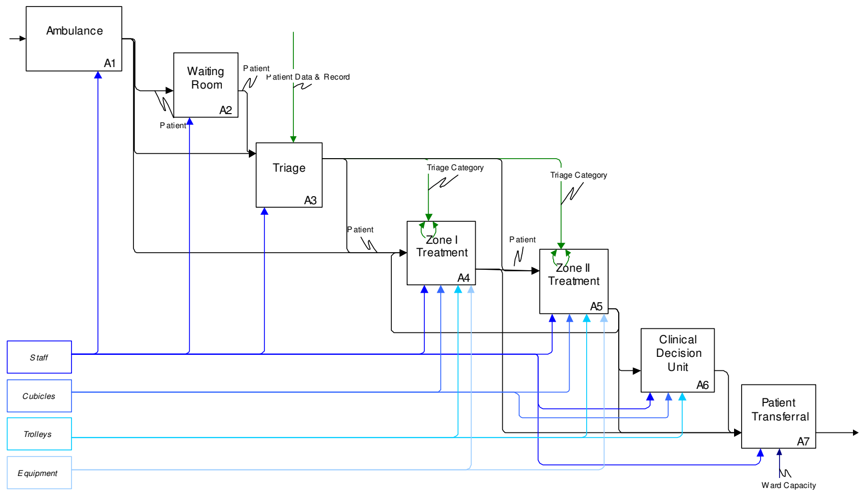
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone I

The basic procedures are similar to Zone II. Zone I is reserved for Chest Pain patients, but in cases of overcrowding of Zone II and Zone I might be used for patients with respiratory ilnesses.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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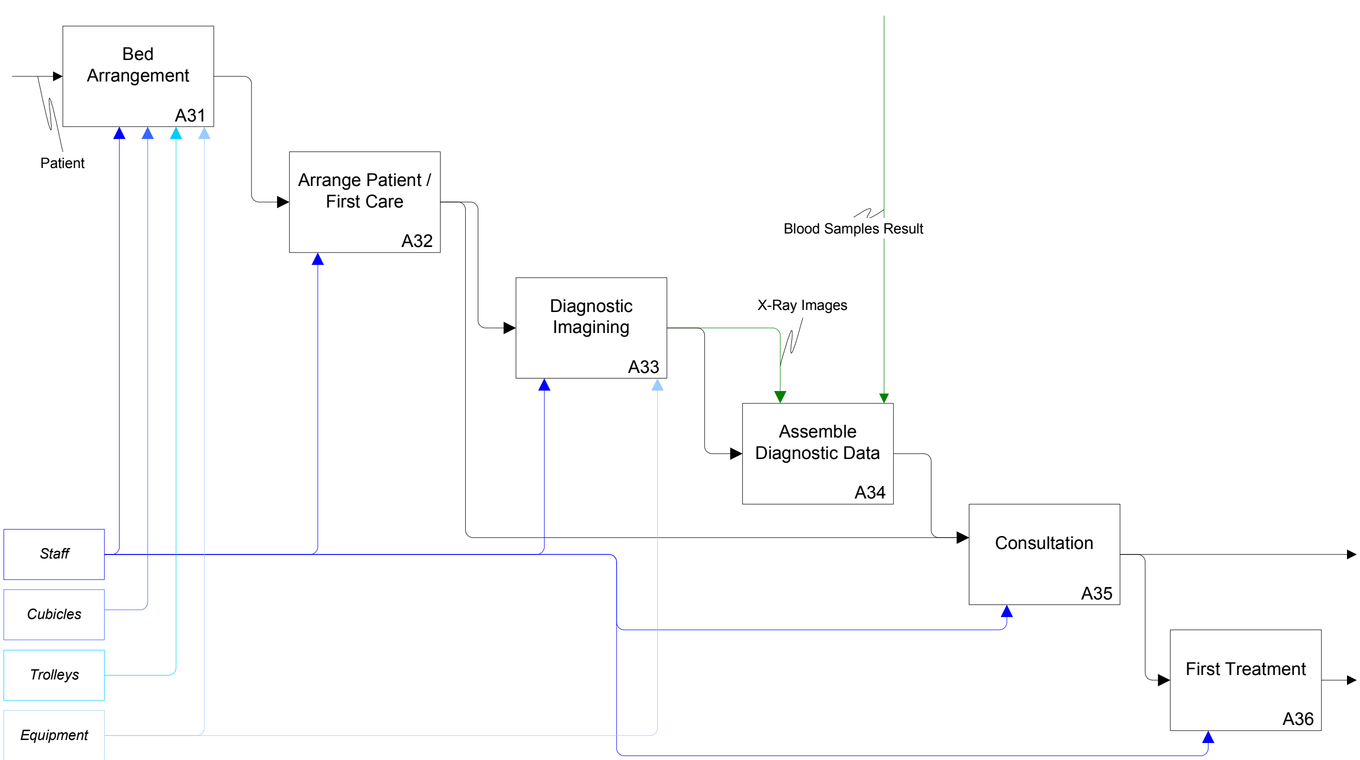

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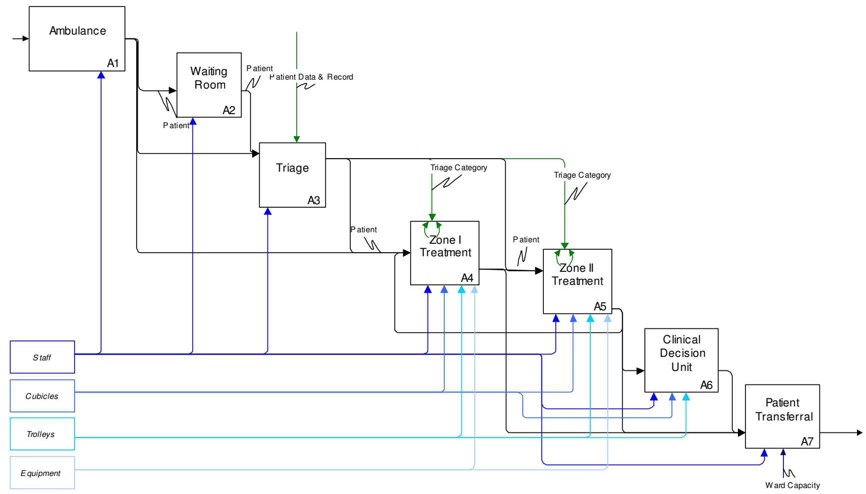
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone II

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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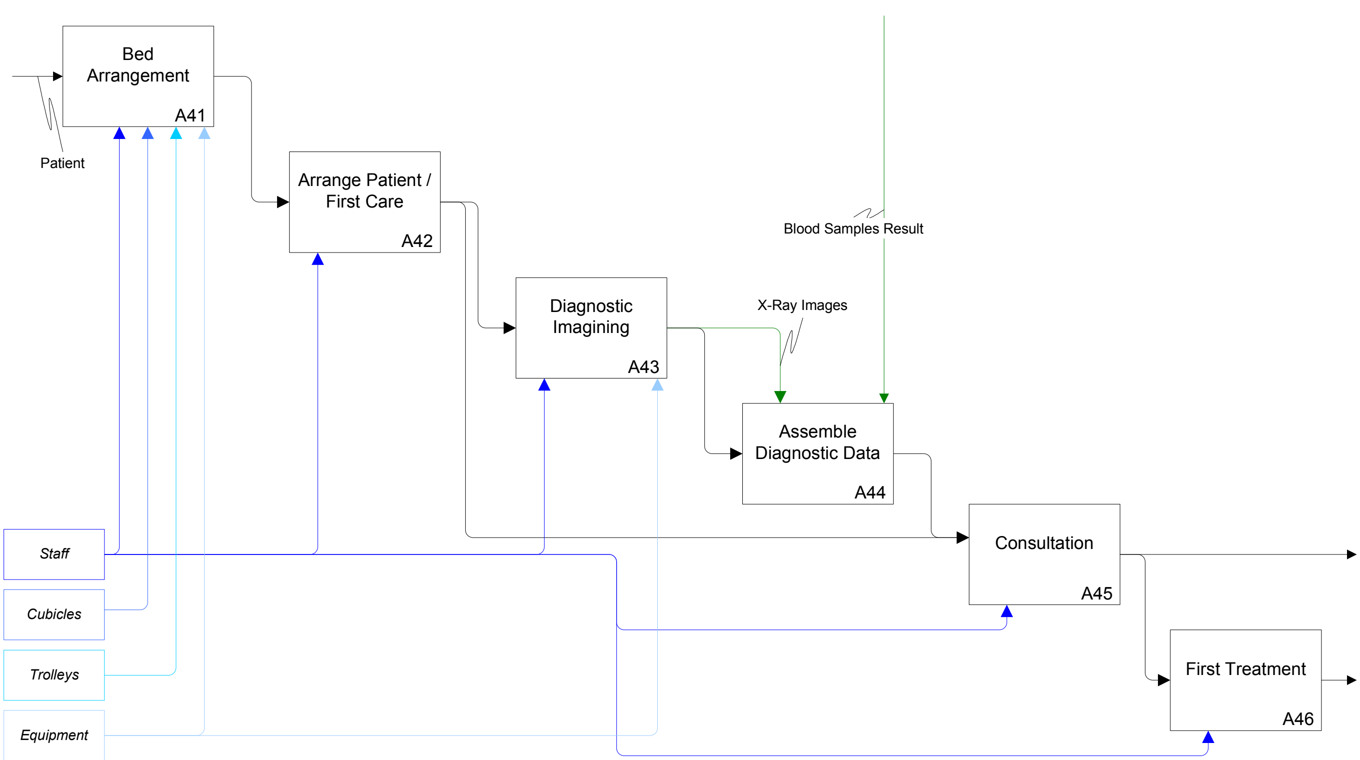

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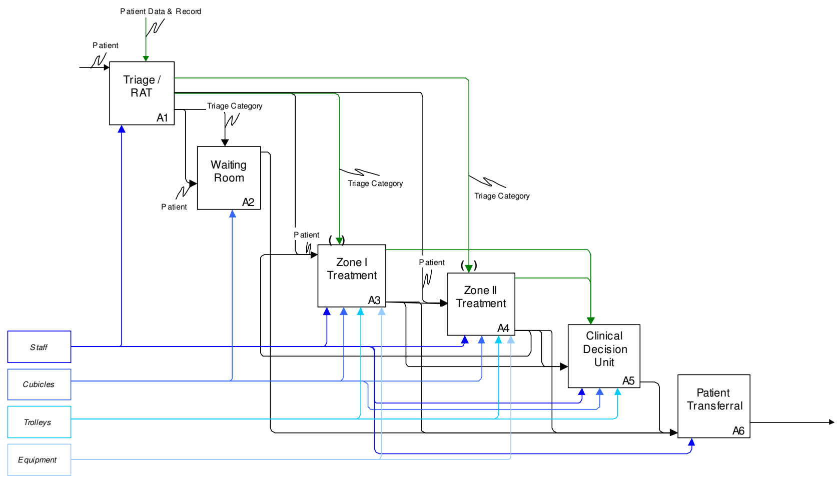
Clinical Decision Unit

The Clinical Decision Unit (CDU) where the final decision is made whether to hospitalize the patients or sent them home. The decision is subject to patient condition and results from a considerable monitoring for the case status.



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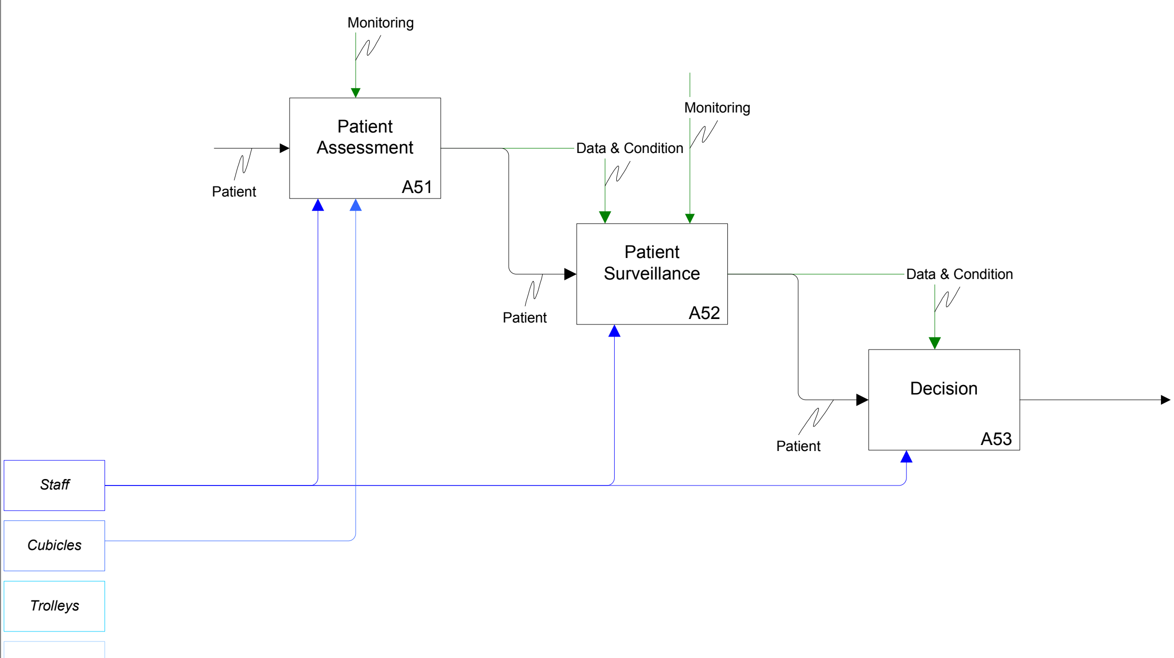

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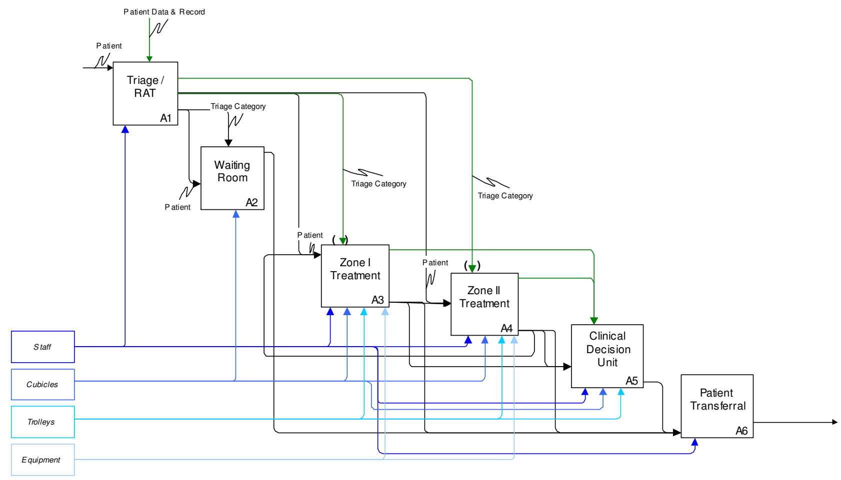
					RECOMMENDED			
	NOTES:				PUBLICATION			

Patient Transferral

In case that the patient is still in a severe condition, the patient will be transferred to the ICU immediately. Otherwise he will be assessed on his current condition.

Before any patient is ready to leave the ED, the patient record will be updated. The patient will either wait in his cubicle or moved to the corridor to free up a cubicle. Nurses usually look after the patient who are supposed to leave the hospital until they will be collected or driven home.



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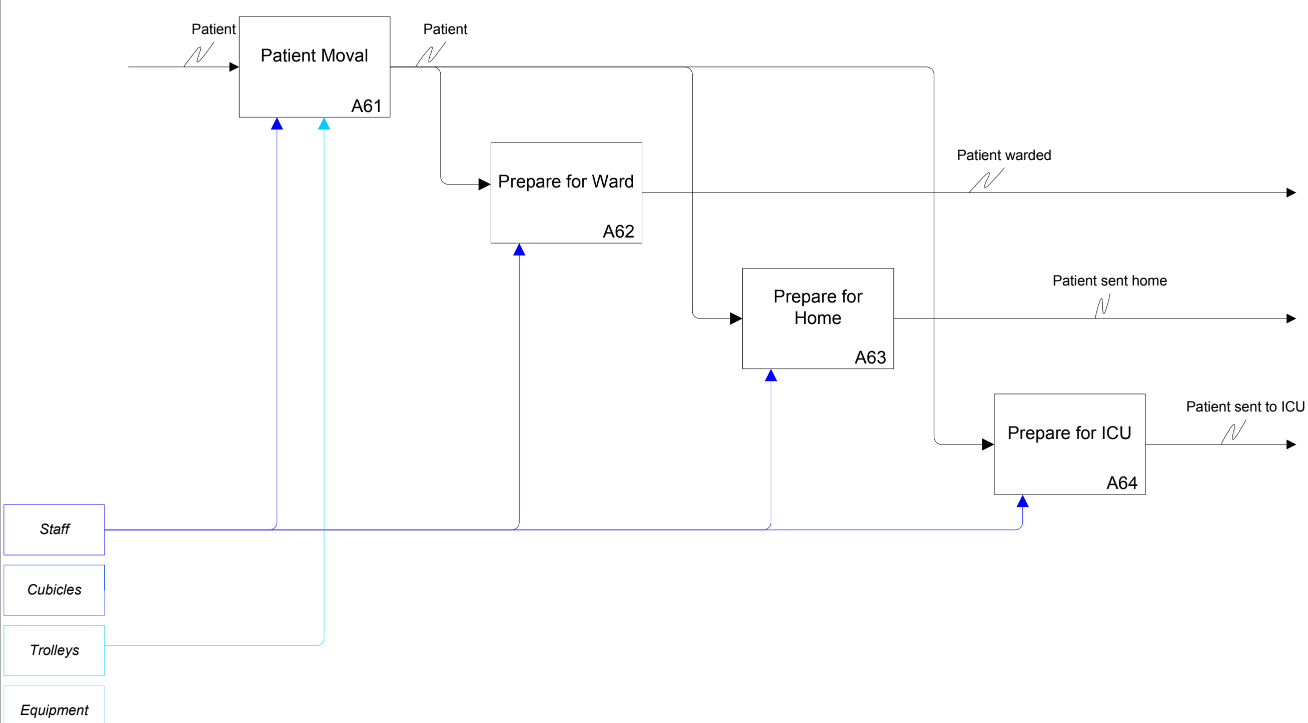

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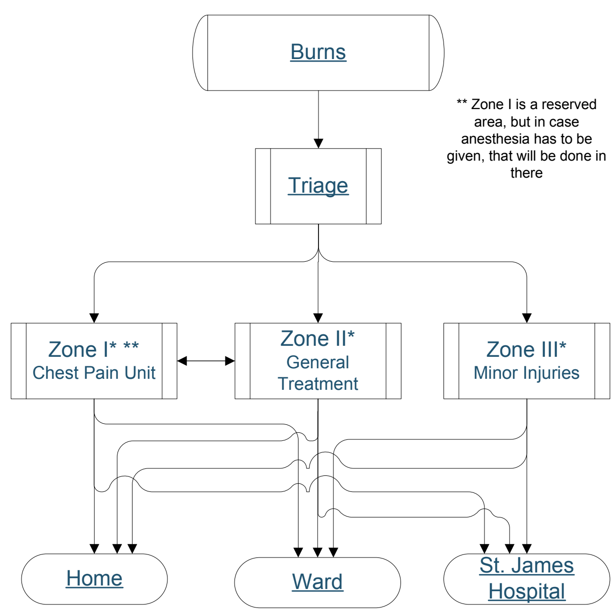
ED in SVUH	PROJECT: PM of ED@SVUH	REV.:	2.0		DRAFT			
					RECOMMENDED			
	NOTES:				PUBLICATION			

Treatment of burns

A specialty unit of the St. James hospital is dedicated to treat injuries caused by burns. The patients are transferred to St. James Hospital as soon as they arrive at the SVUH. First immediate treatment will be done in the ED. Patients with burns are usually sent straight to Zone I where they wait for transferral. During this wait, their burns are treated. The usual common pathway is that the patient goes to Zone I and wait for their transferral to the St. James hospital. One of the other Zones might be used if Zone I is fully occupied. All other routing is likely but uncommon.



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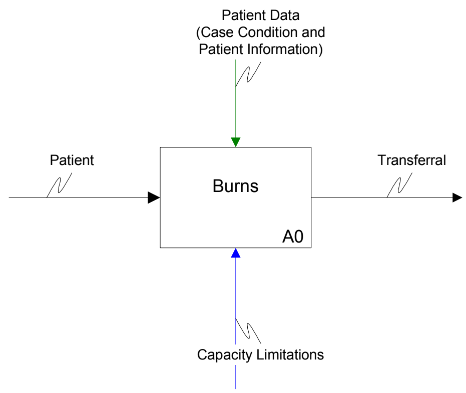

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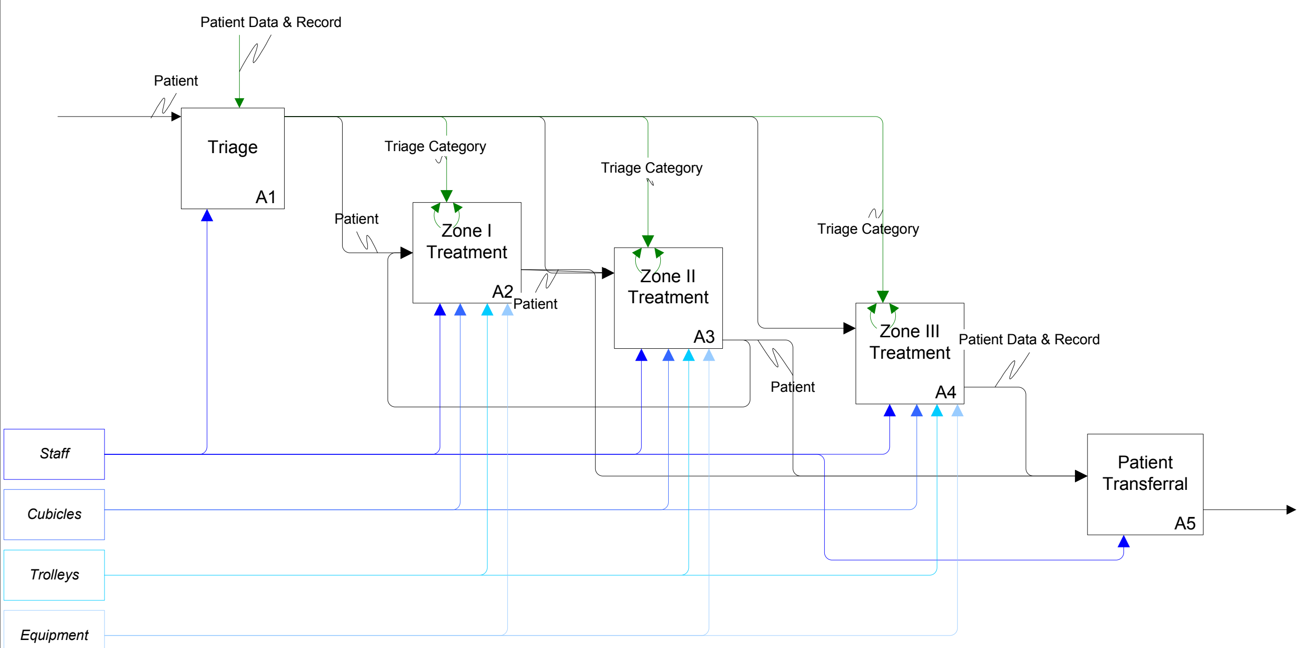

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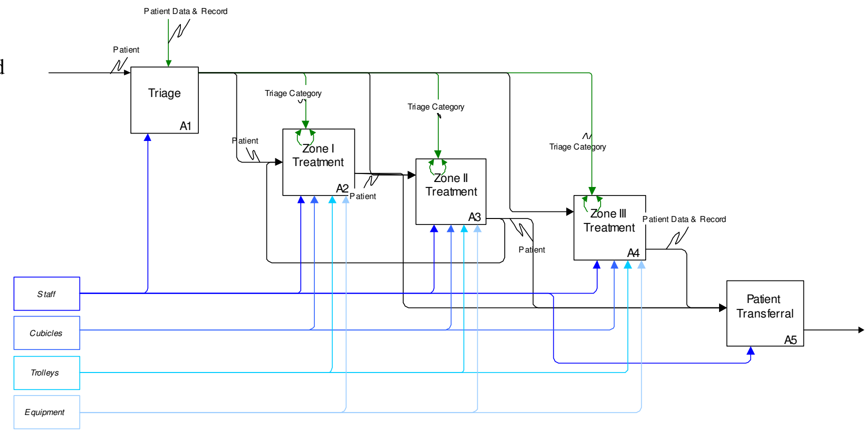
	NOTES:			PUBLICATION			

Triage

The triage for patients with burns is done by the triage team. The patient is assessed based on the accident and a patient record is made. The details obtained from the patient are then handed to the administrational staff. Blood samples are taken as soon as the patient is in a safe environment. The administrational staff is then arranging an appointment for X-Ray. All the findings and diagnostic results are stored in a patient record.



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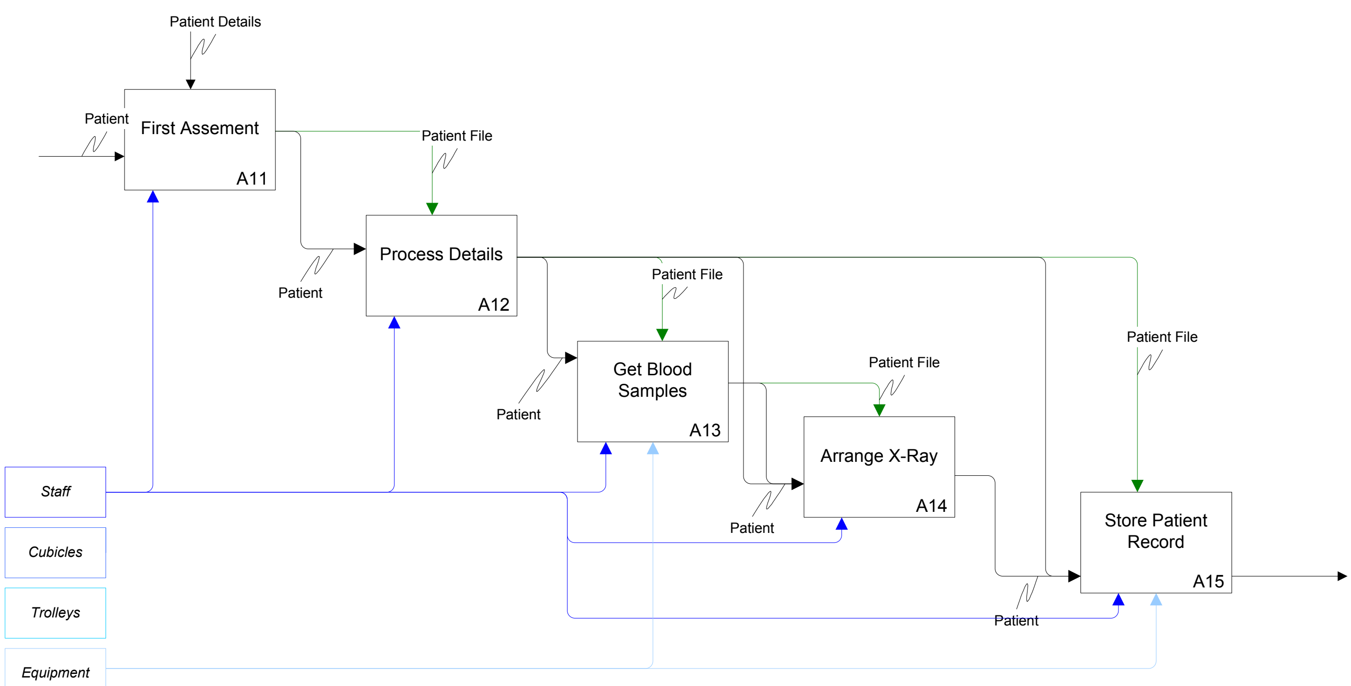

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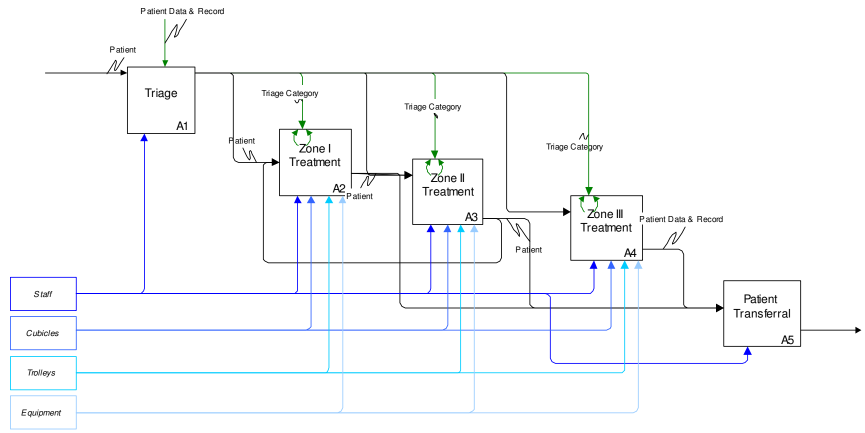
RECOMMENDED
NOTES: | PUBLICATION

Zone I

The basic procedures are similar to Zone II. Zone I is reserved for Chest Pain patients.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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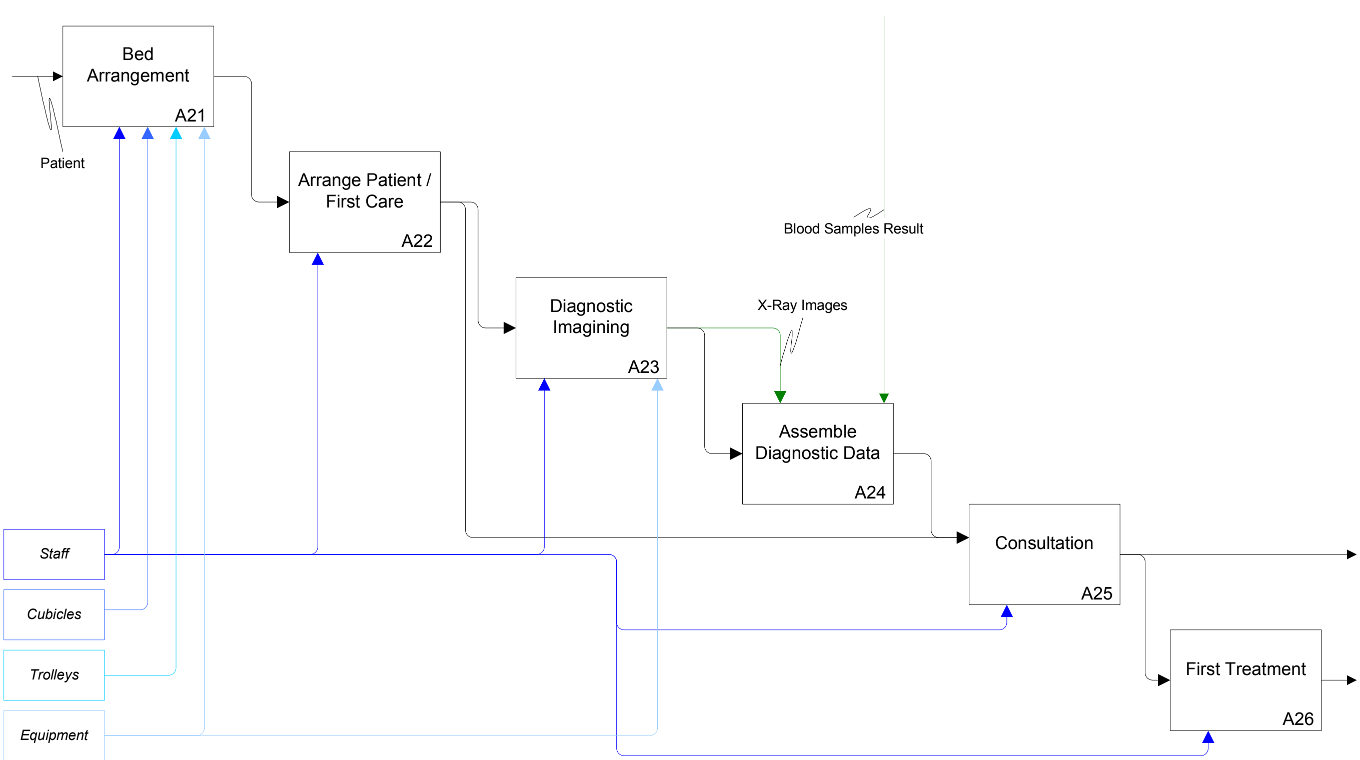

NODE: A2 | TITLE: Zone I Treatment A2 | NO.: 10

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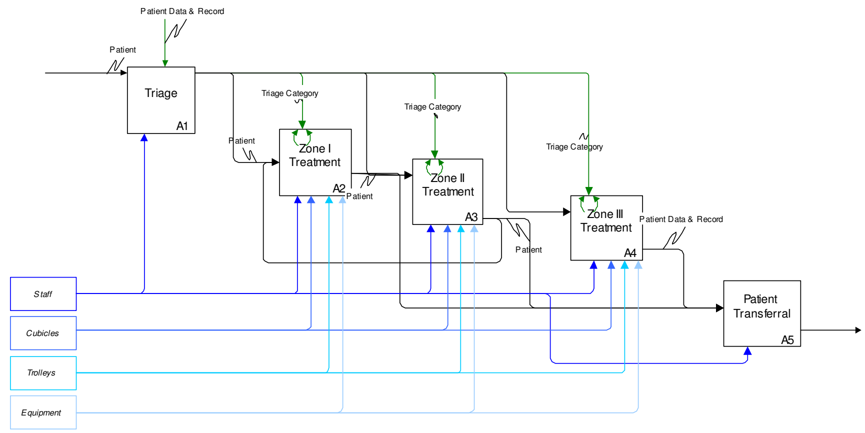
	NOTES:			PUBLICATION			

Zone II

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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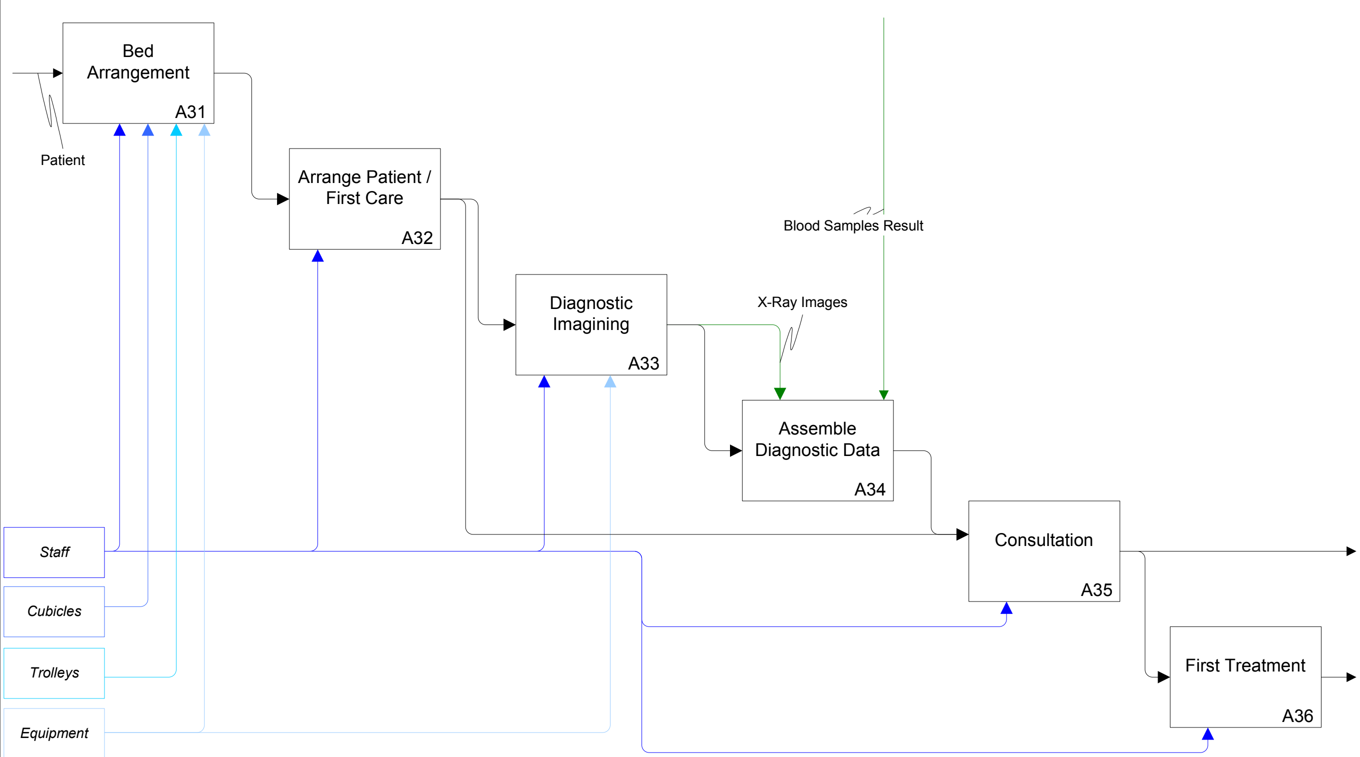

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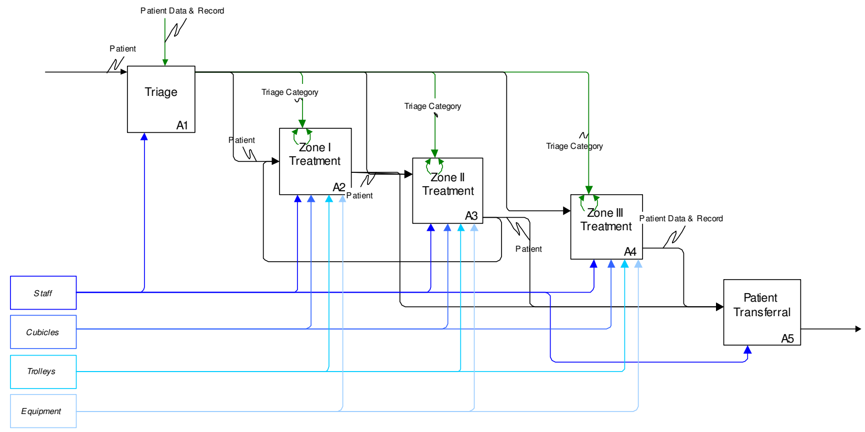
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone III

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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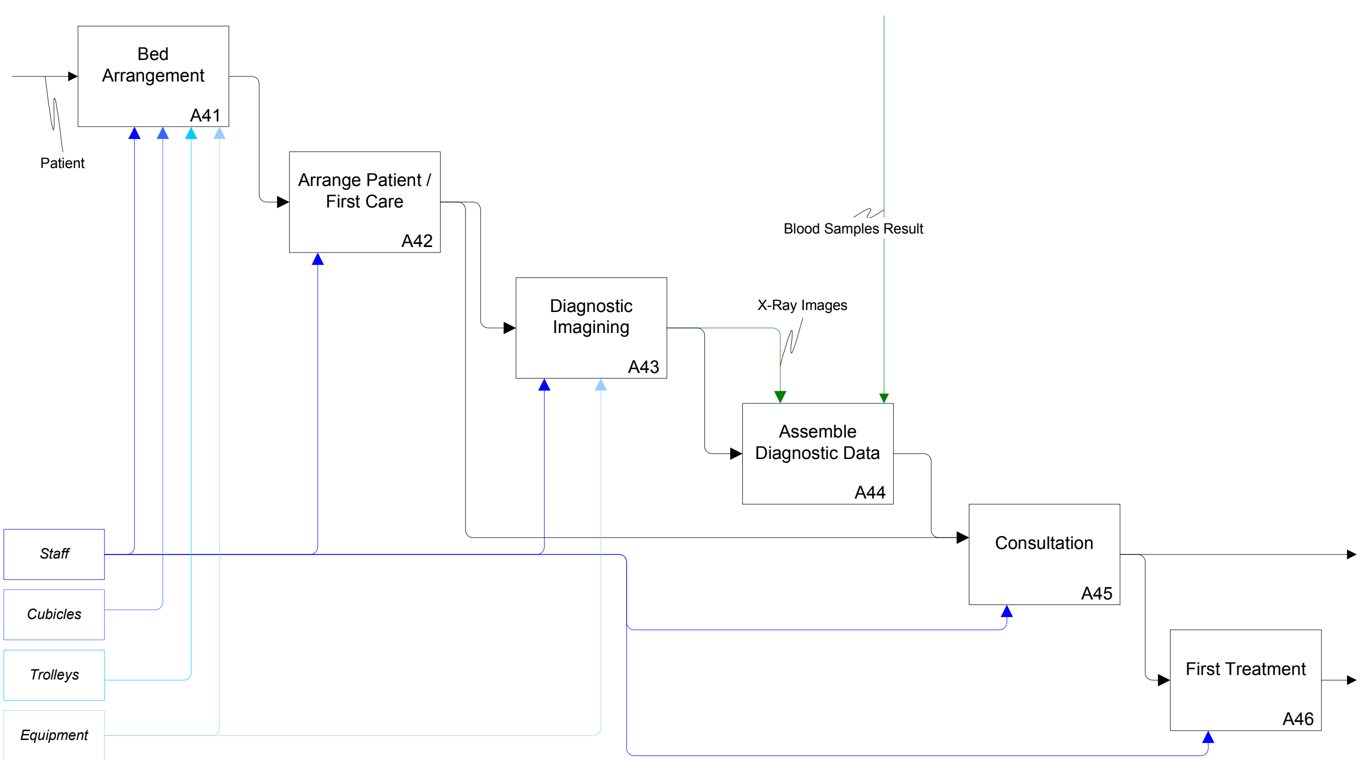

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ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
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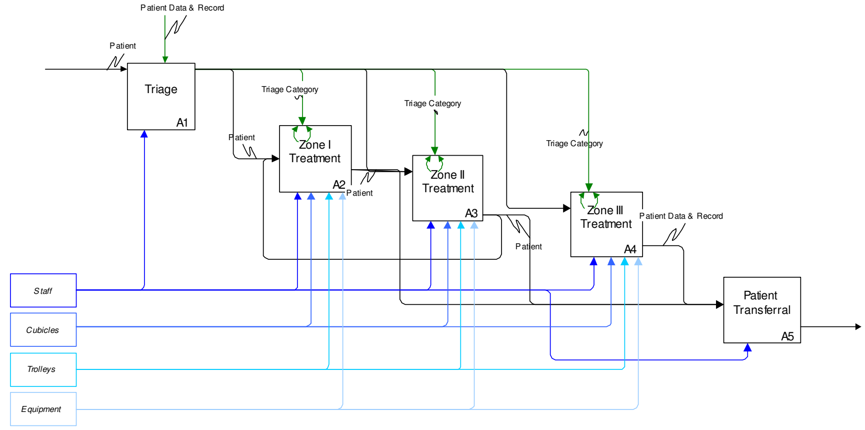
	NOTES:			PUBLICATION			

Patient Transferal

Before any patient is ready to leave the ED, the patient record will be updated. The patient will either wait in his cubicle or moved to the corridor to free up a cubicle. Nurses usually look after the patient who are supposed to leave the hospital until they will be collected or driven home.



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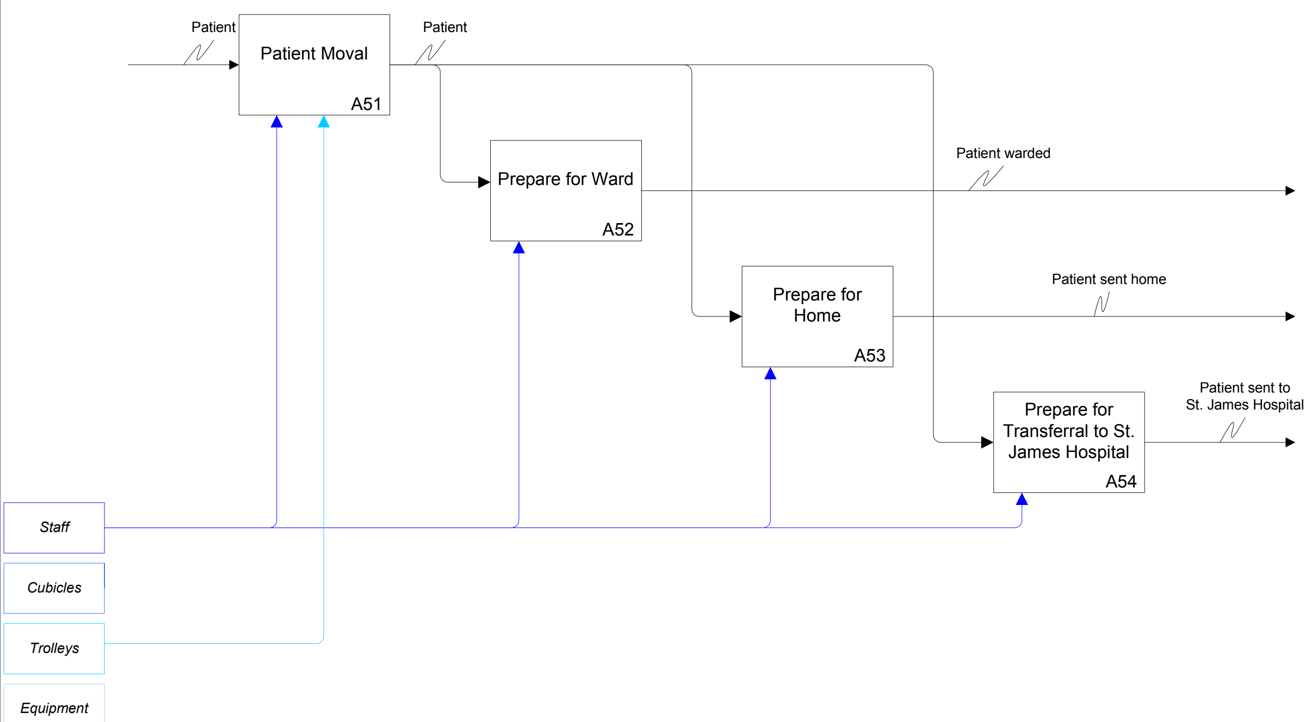

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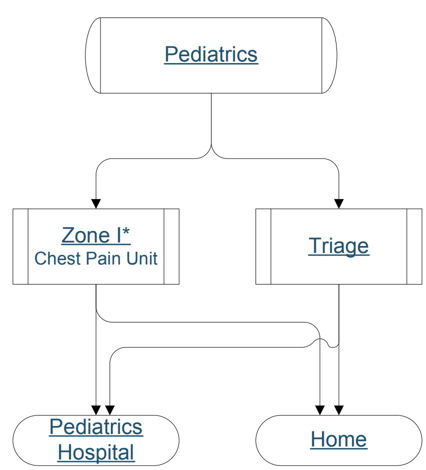
	NOTES:				PUBLICATION			

Treatment of Paediatrics

The SVUH is not intended to treat paediatrics, but usually they are accepted and receive first treatment if necessary. At the registration parents will be advised to go to a paediatrics hospital, but triage and assessments will be done. If necessary treatment will be done at Zone I. As soon as the patient is in a safe condition the patient will be transferred.



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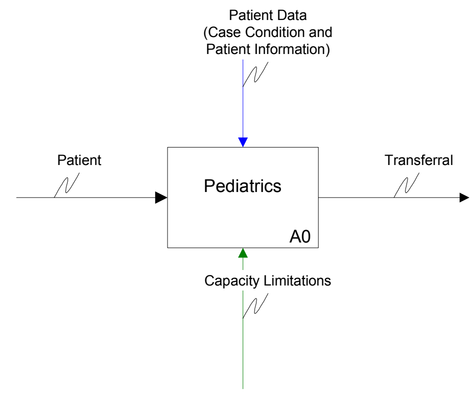

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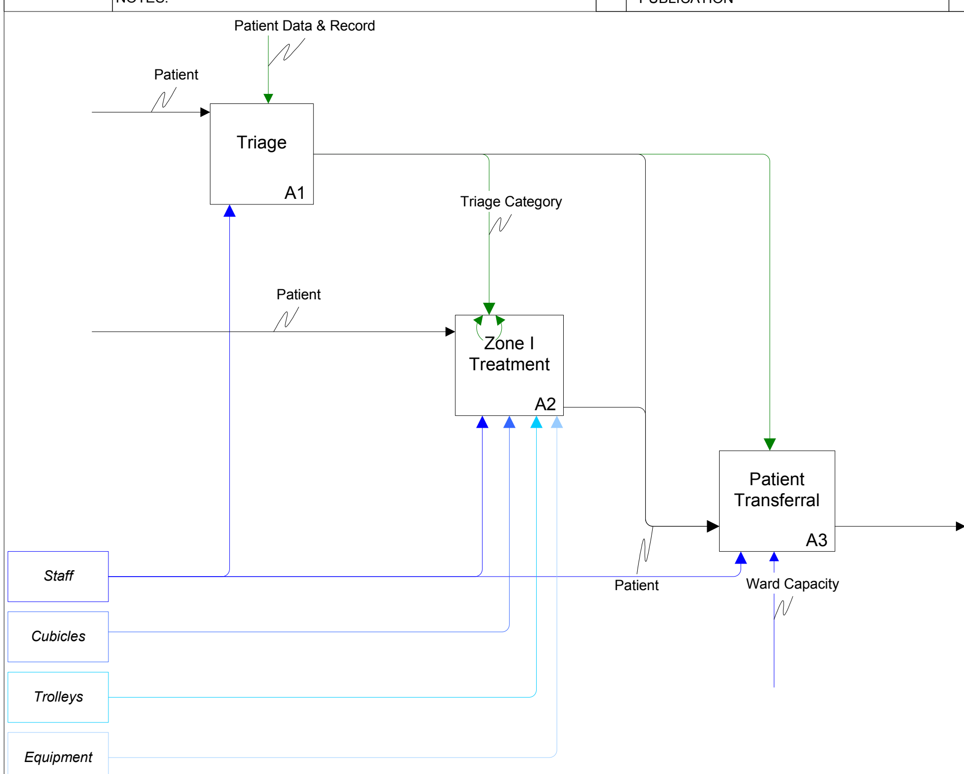

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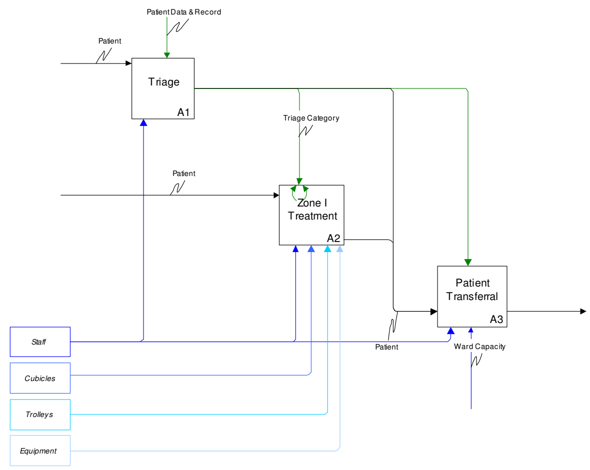
Triage

The patient is assessed onto the nature of his case and a patient record is made. The details obtained from the patient or relatives are then handed to the administrational staff. The triage team decides whether blood samples or X-Rays are needed. Blood samples are taken as soon as the patient is in a safe environment. The administrational staff is then arranging an appointment for X-Ray. All the findings and diagnostic results are stored in a patient record.



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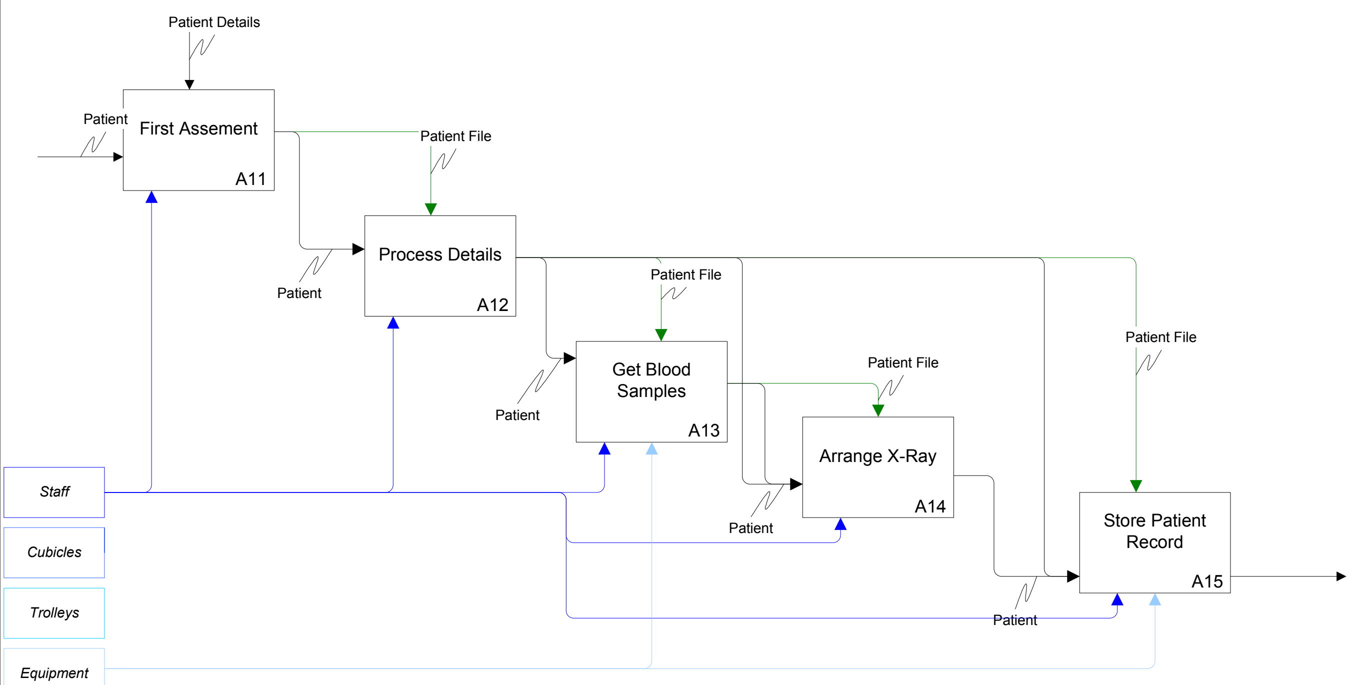

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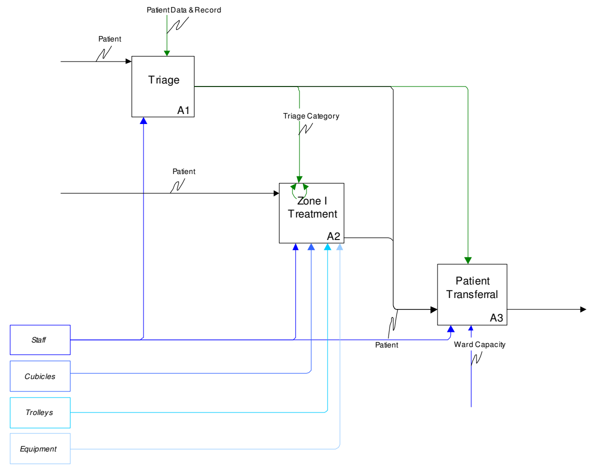
	NOTES:			PUBLICATION			

Zone I

The Zone I is reserved for Chest Pain patients.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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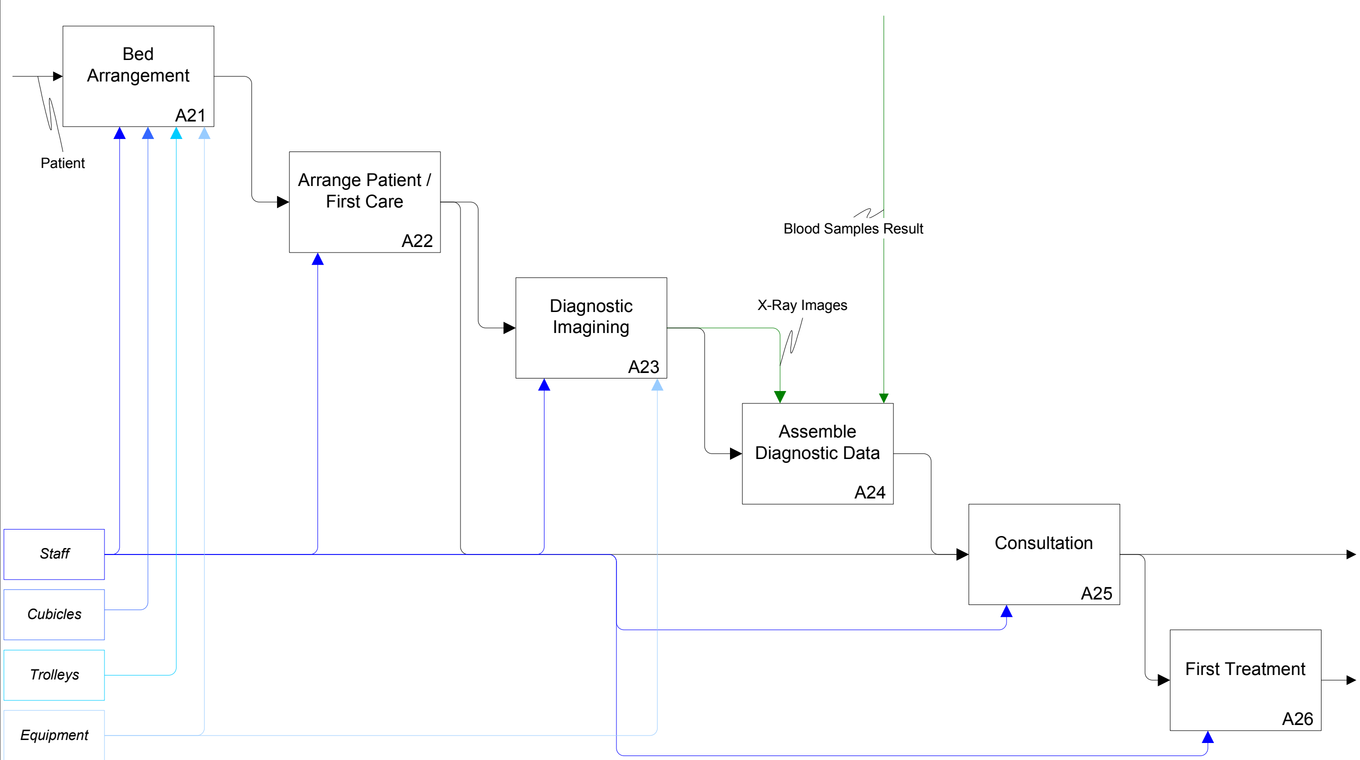

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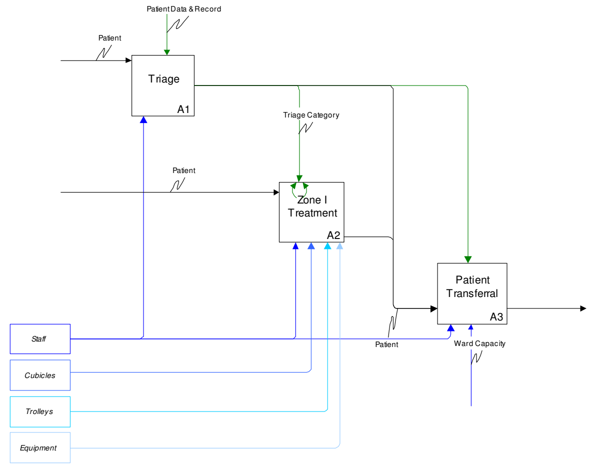
	NOTES:			PUBLICATION			

Patient Transferral

Before any patient is ready to leave the ED, the patient record will be updated. The patient will either wait in his cubicle or moved to the corridor to free up a cubicle. Nurses usually look after the patient who are supposed to leave the hospital until they will be collected or driven home.



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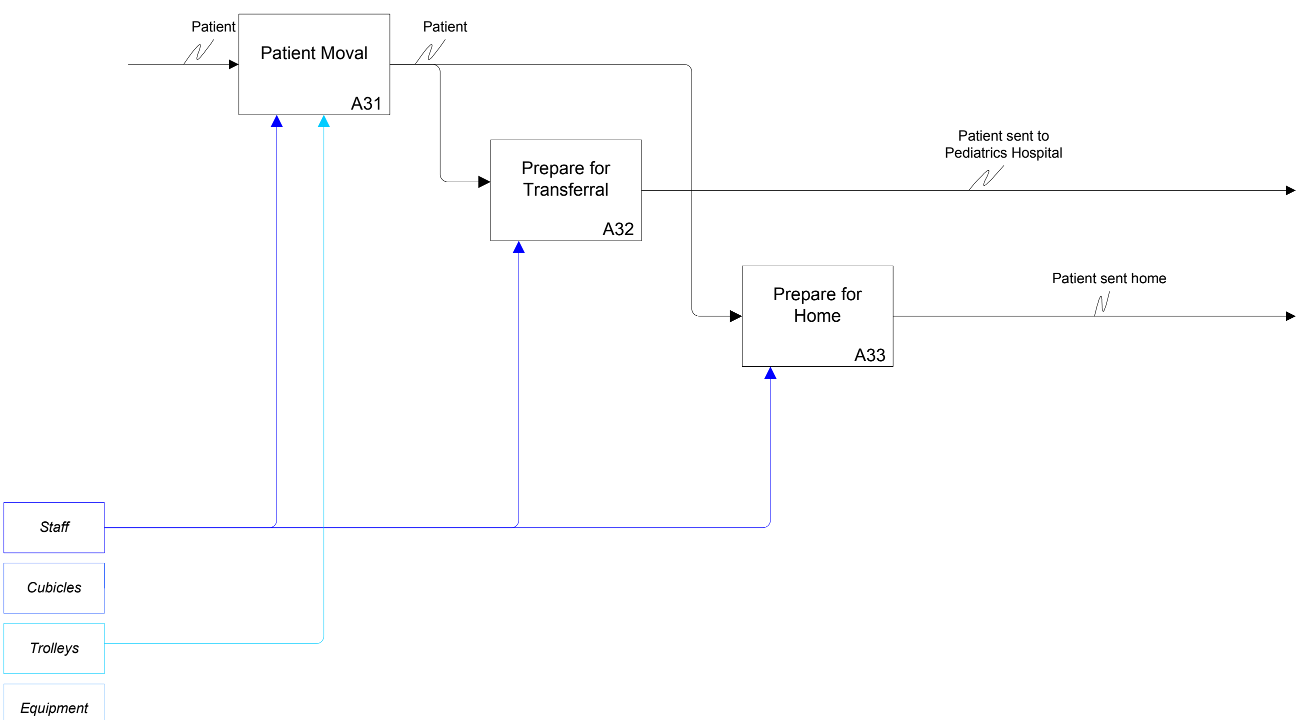

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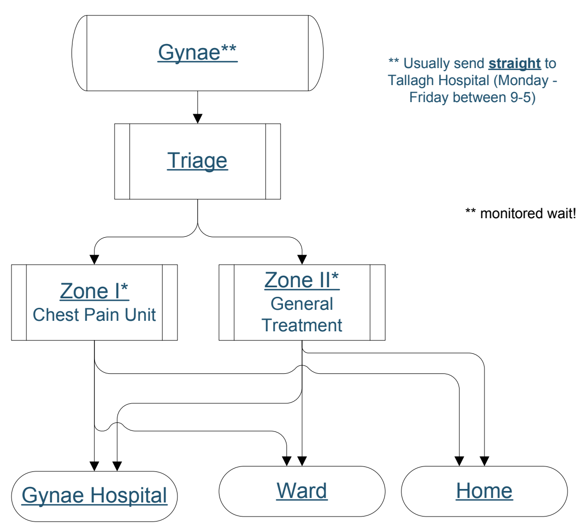
Treatment for patients with gynaecological problems

Patients showing symptoms of gynaecological failure are usually sent straight to Tallagh Hospital. The Tallagh hospital only accepts patients during opening hours (Monday to Friday between 9 am and 5 pm). When patients arrive at SVUH ED they are monitored until they can be transferred.
The patient is being triaged and a category level will be determined. Depending on the time the patient will be transferred to the 'gynae' hospital. The wait until the transferral will be monitored either in Zone I or II depending on their severity. In case of bed capacity of the ward being available, the patient will be warded for his wait. In case of a low triage category and busy ED the patient will be transferred home.



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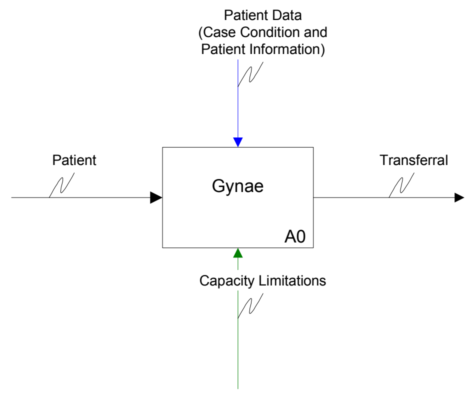

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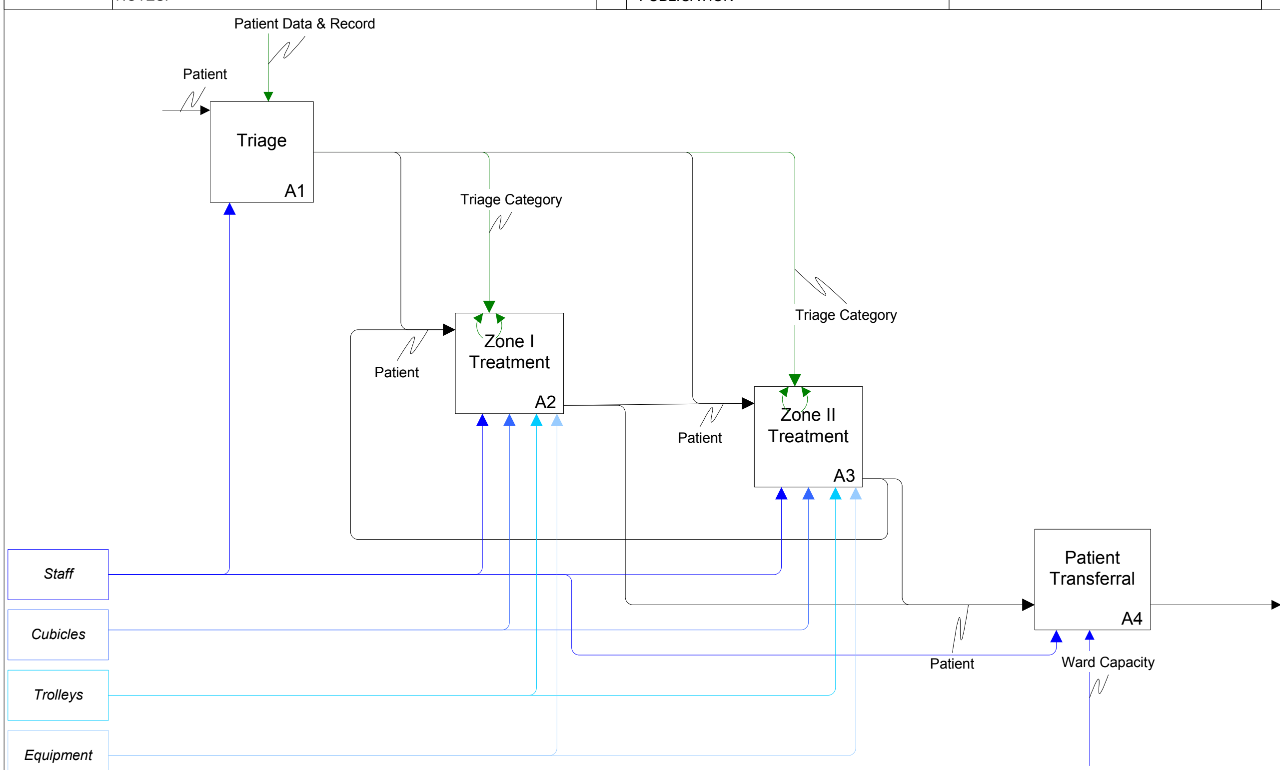

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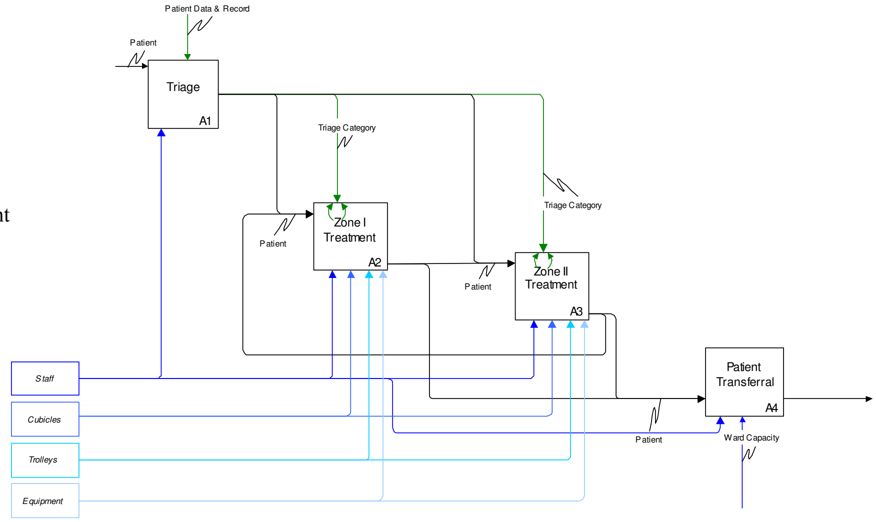
				RECOMMENDED			
	NOTES:			PUBLICATION			

Triage

The triage procedure for patients gynaecological problems is done by the triage team. The patient is assessed onto the nature of his case and a patient record is made. The details obtained from the patient or relatives are then handed to the administrational staff. The triage team decides whether blood samples or X-Rays are needed. Blood samples are taken as soon as the patient is in a safe environment. The administrational staff is then arranging an appointment for X-Ray. All the findings and diagnostic results are stored in a patient record.



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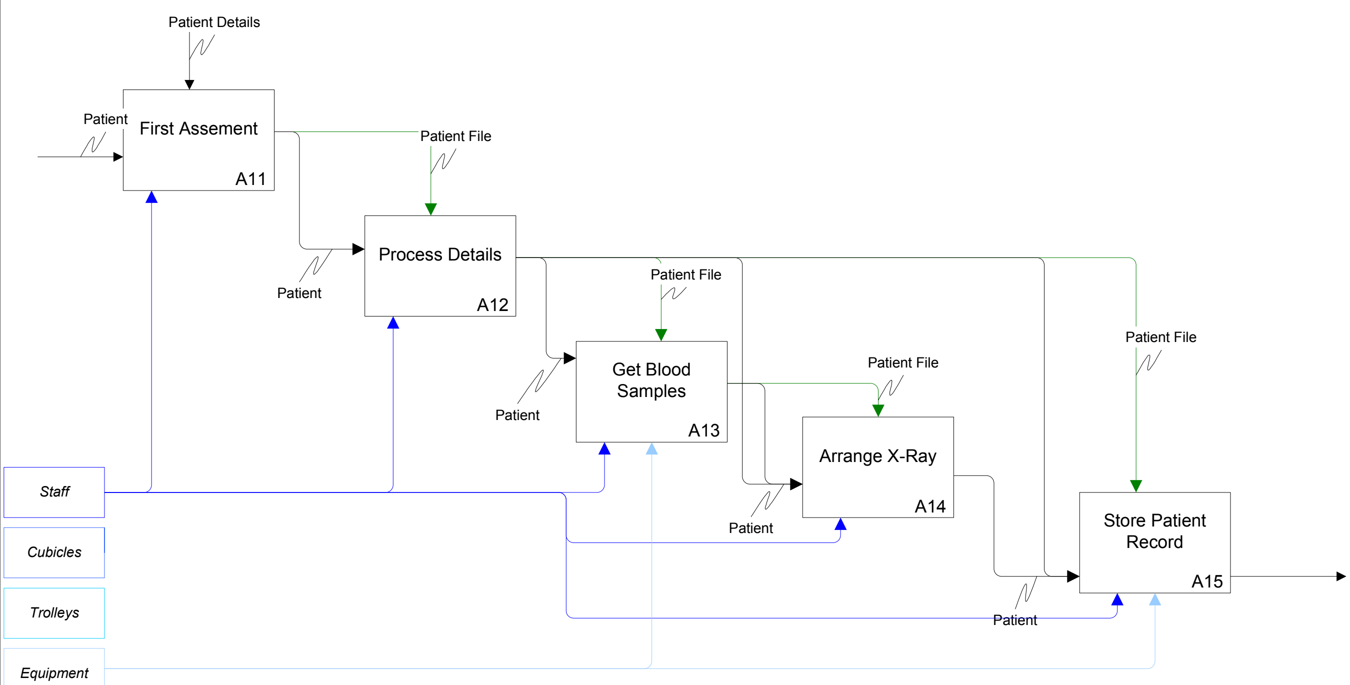

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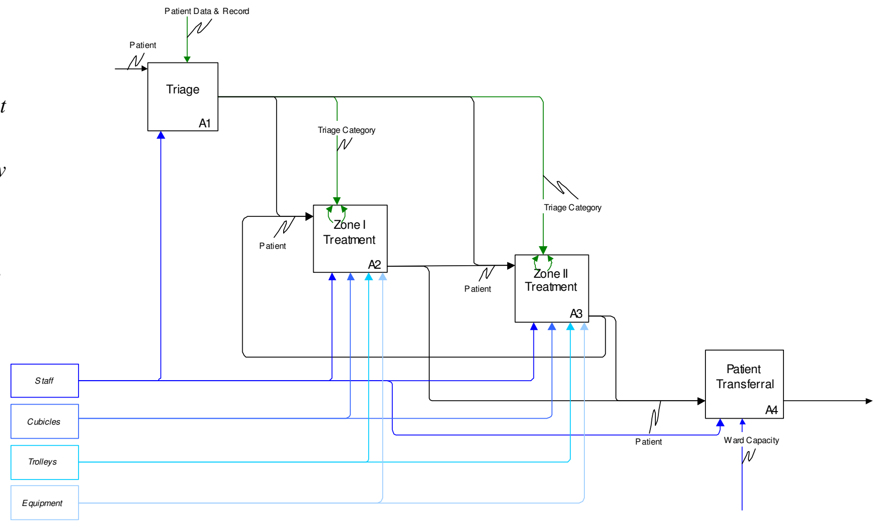
	NOTES:			PUBLICATION			

Zone I

The Zone I is reserved for Chest Pain patients.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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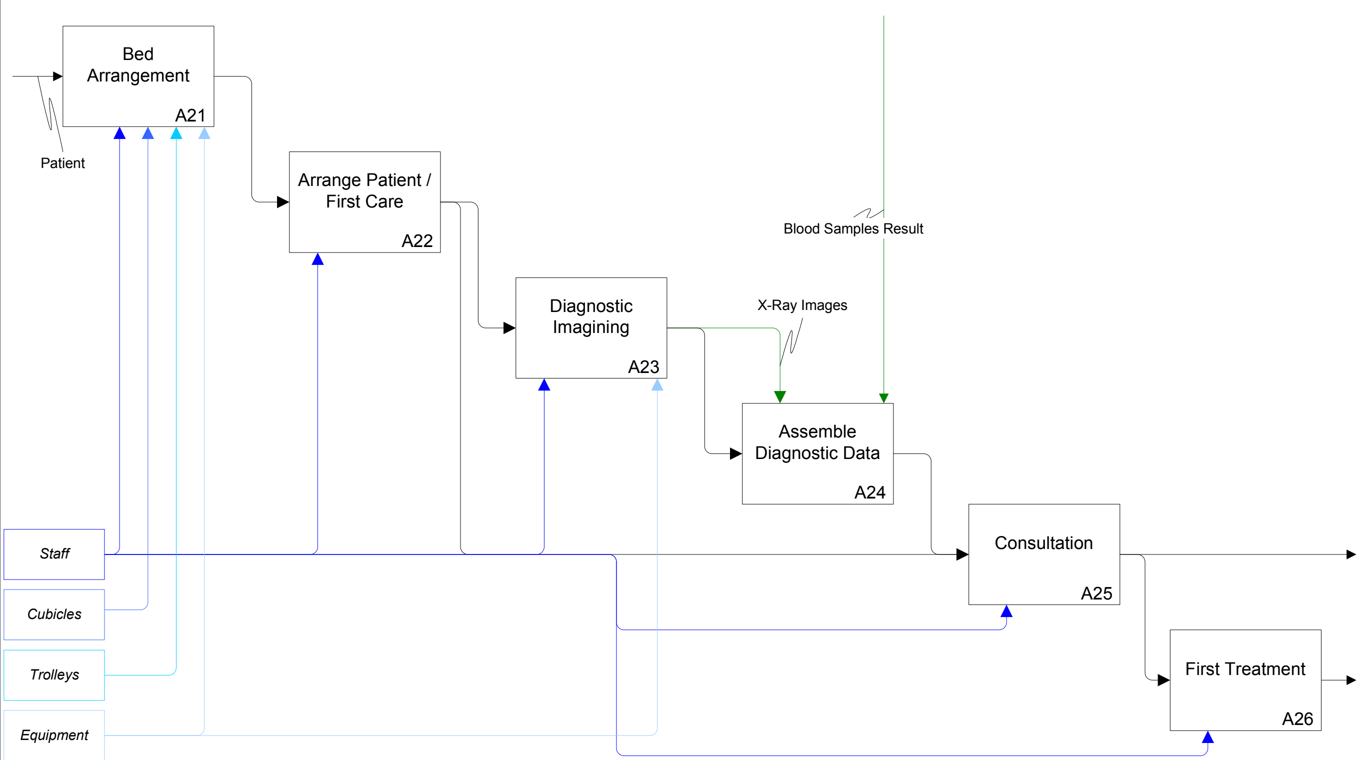

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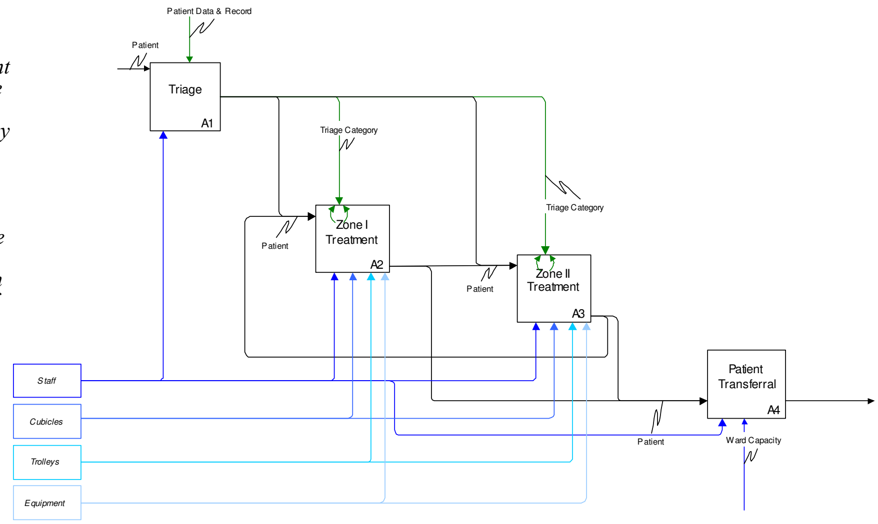
Zone II

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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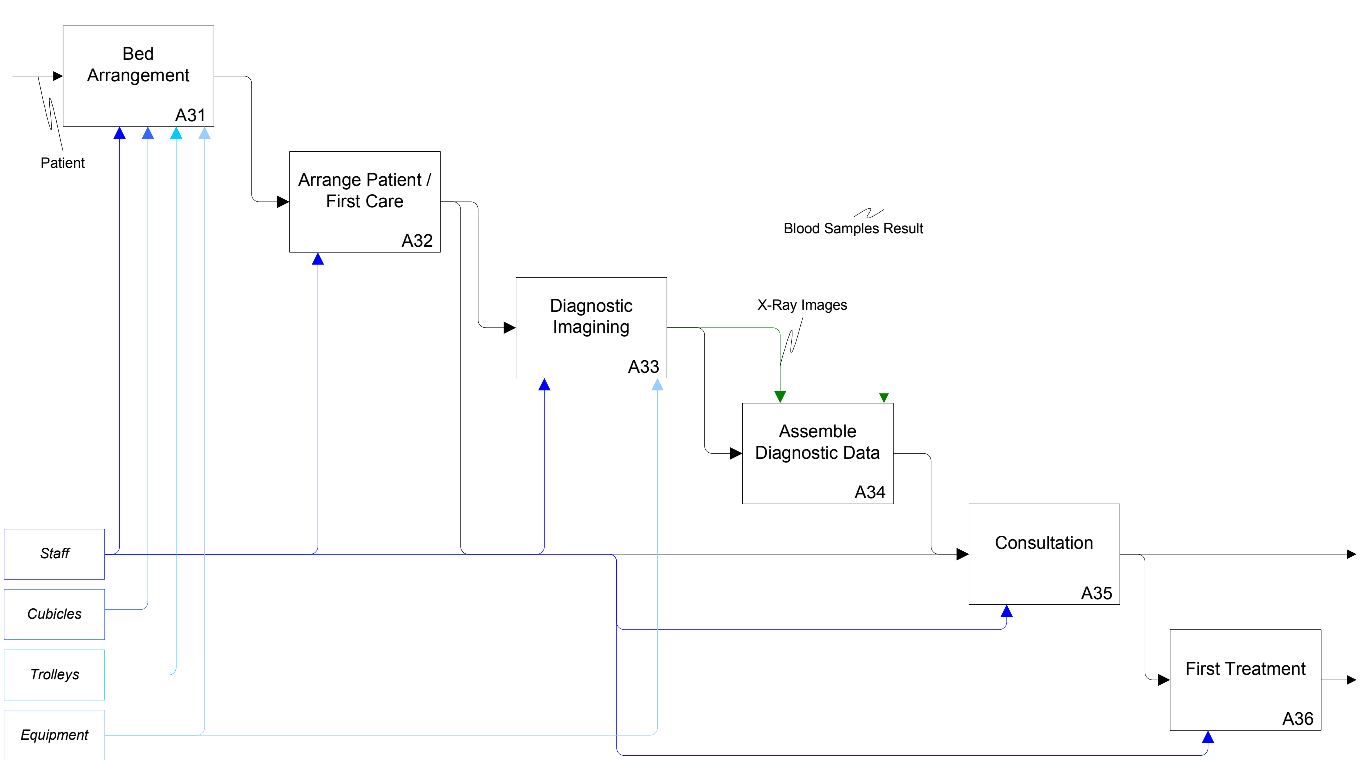

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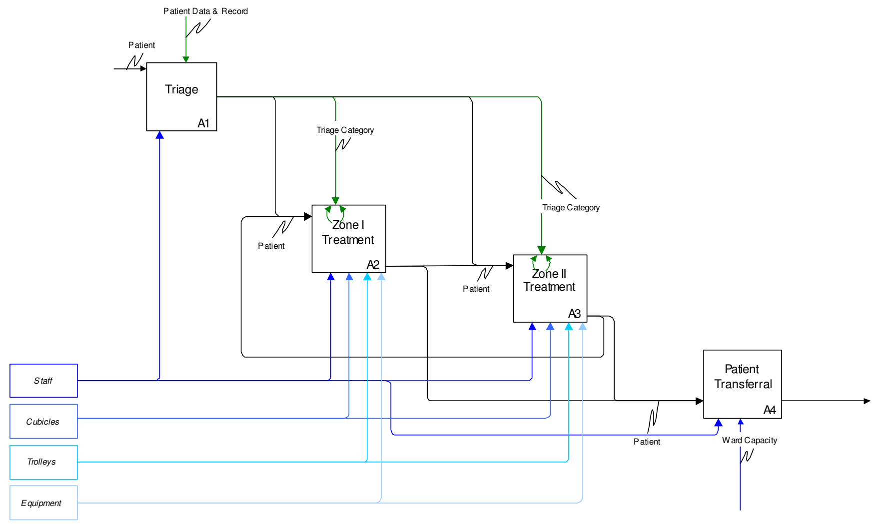
	NOTES:			PUBLICATION			

Patient transferral

Usually patients with gynaecological problems are sent to the Gynae Clinic as soon as the opening hours allows a save transferral; these patients are rarely warded. They are usually sent to a Gynae Clinic. In low severity cases patients are sent home, to see their GP for further treatment (also uncommon).



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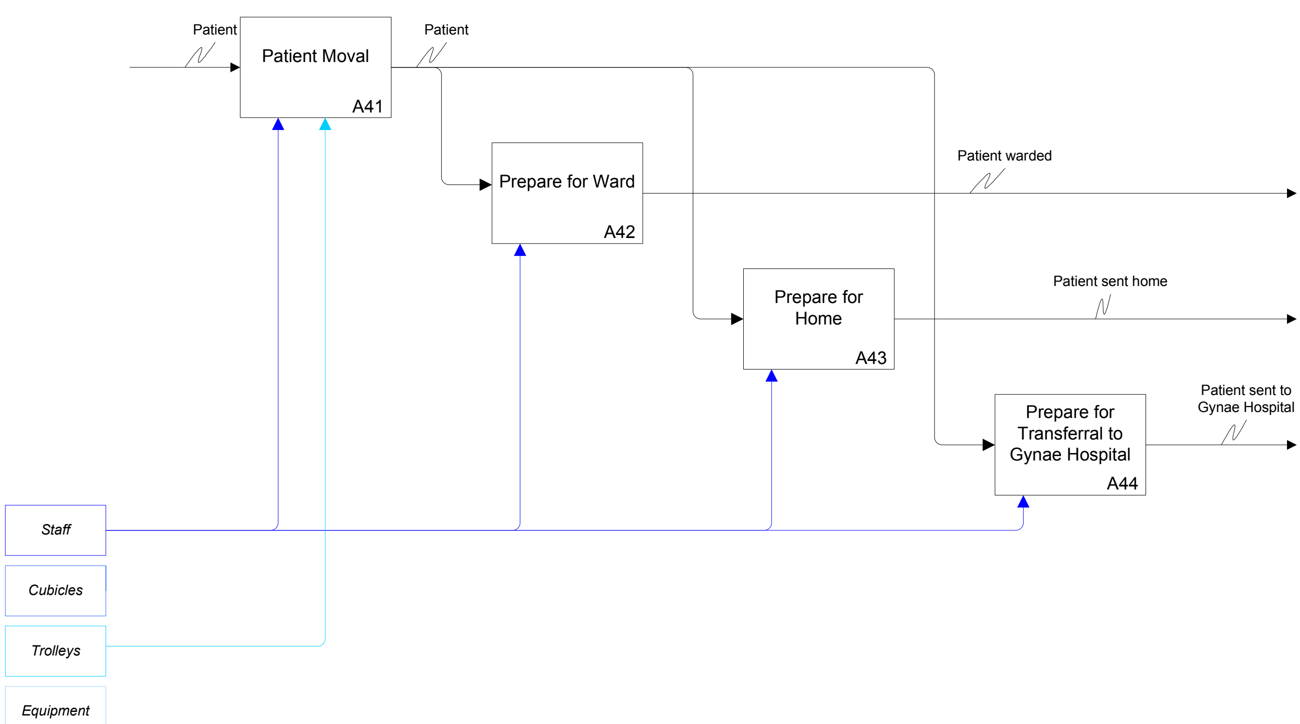

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ED in SVUH	PROJECT: PM of ED@SVUH	REV.:	2.0		DRAFT			☐
					RECOMMENDED			
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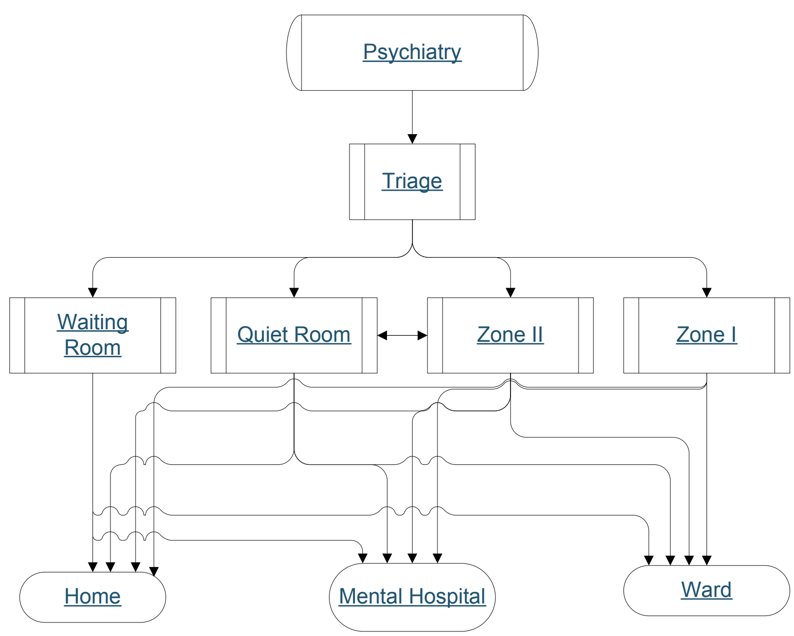
Treatment of patient with psychological problems

These patients are treated due to the possibility of a previous head injury / organ failure / tumour in the brain. These possibilities have to be checked, while the patient might be of special need for silence. Triage is assessing and checking for each possibility. Depended of the need of the patient, the patient will either be sent to back to the waiting room, to the quiet room, Zone I or Zone II. Patients located in Zone II may be sent to the quiet room, or the other way round if necessary. Further assessments, like X-Ray or CT scan, blood samples will determine whether the patient will be transferred. The patient can be sent home, to the ward or to a mental hospital.



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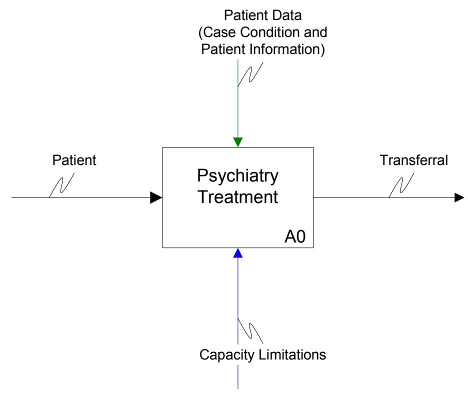

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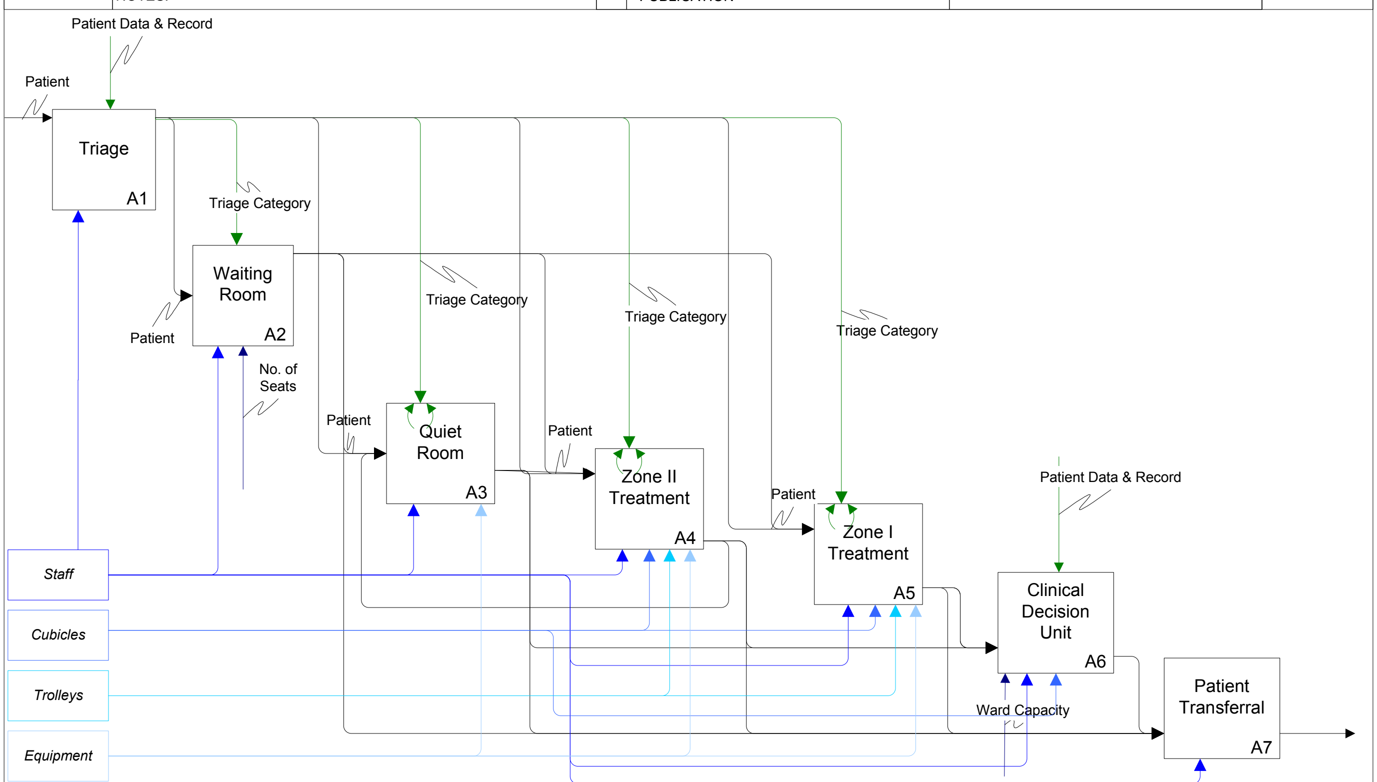

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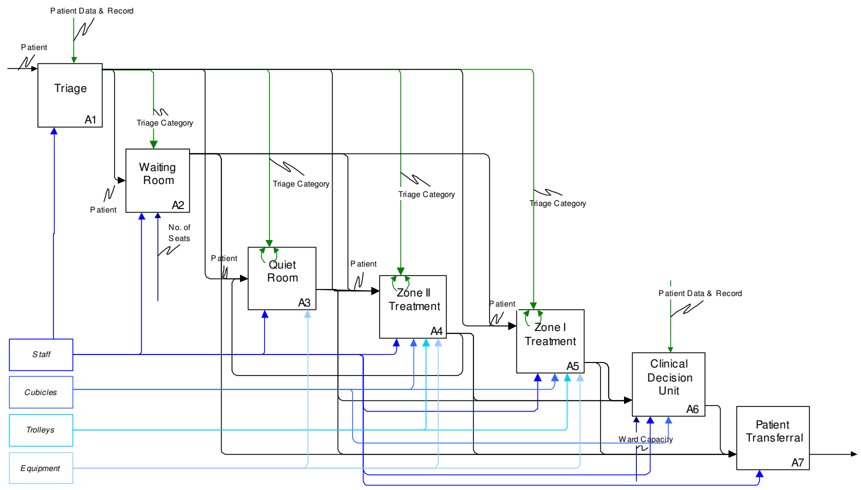
	NOTES:			PUBLICATION			

Triage

The triage of patients with psychiatric problems is done by the triage team. The patient is assessed based on the accident and a patient record is made. The details obtained from the patient are then handed to the administrational staff. Blood samples are taken as soon as the patient is in a safe environment. The administrational staff is then arranging an appointment for X-Ray. All the findings and diagnostic results are stored in a patient record.



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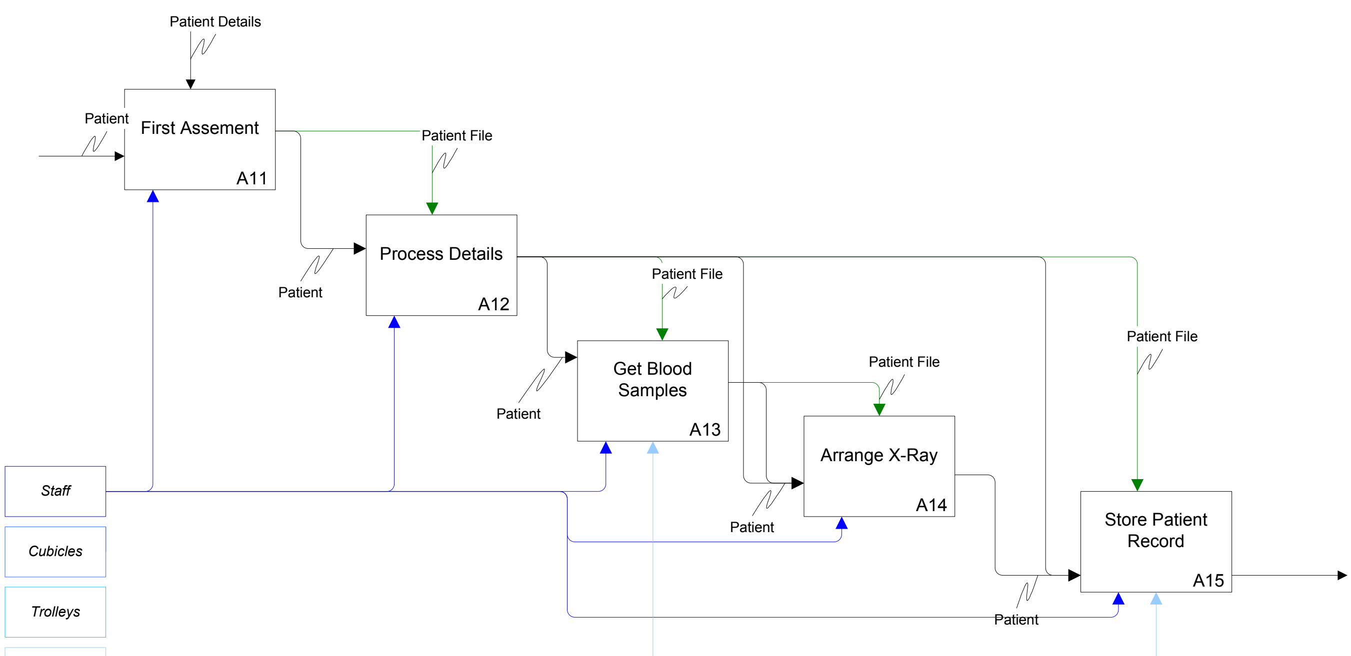

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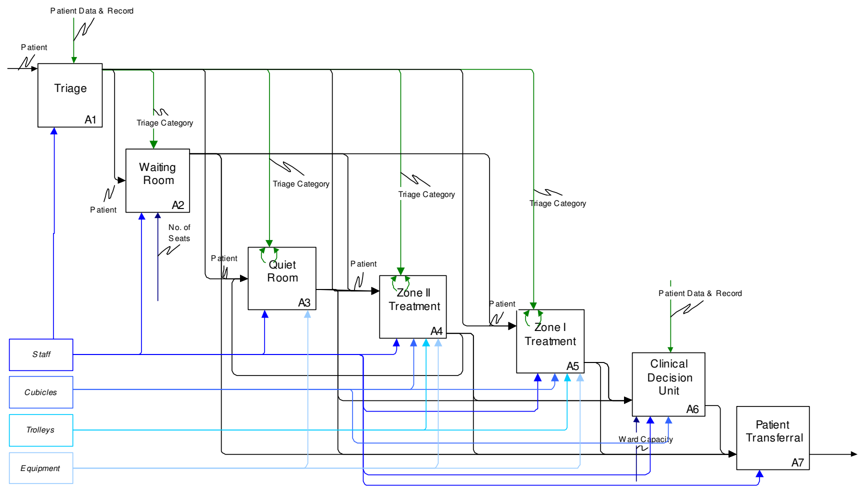
Waiting Room

In low severe cases and full capacity of the ED the patient will be sent back to the waiting room. Patient waits for X-Ray. After X-Ray the patients have to wait in a preset location to discuss their cases.



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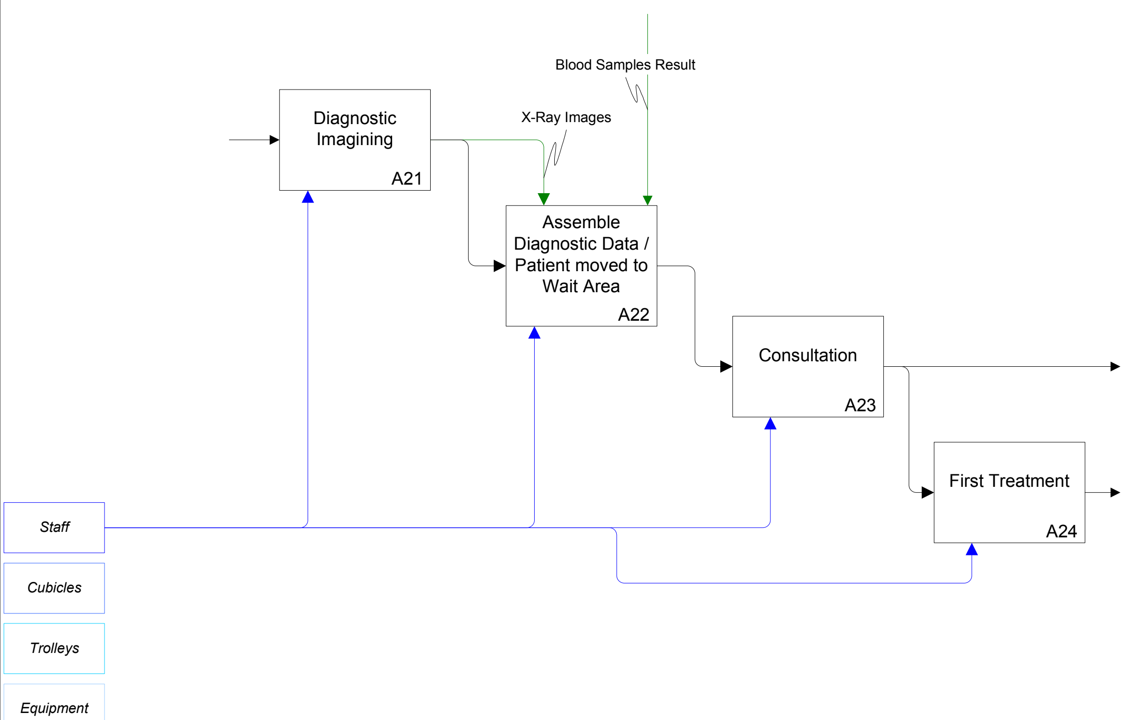
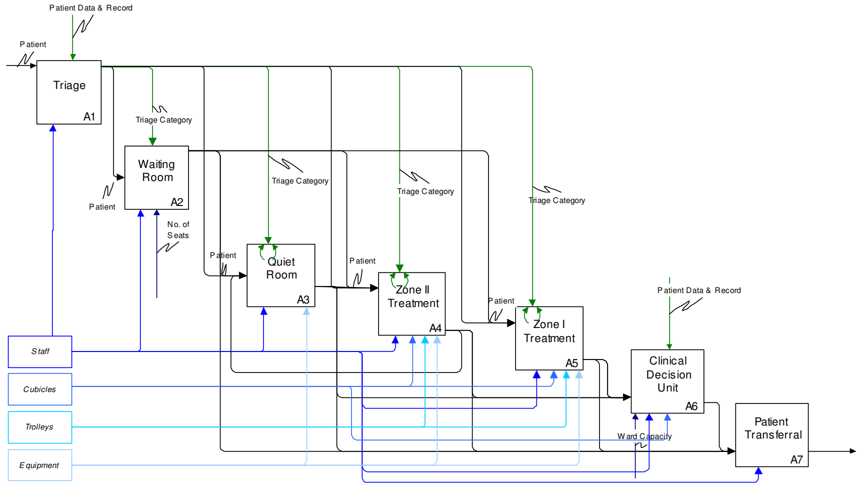


NODE: A2	TITLE: Wait Room A2	NO.: 13

USED AT:	AUTHOR:	DATE: 17/04/2008	X	WORKING	READER	DATE	CONTEXT:
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Quiet Room

Patients that are easily distracted and disturbed by the noise of the ED are placed in the quiet room.



NODE: A0	TITLE: Psychiatry Treatment A0	NO.: 13

USED AT:	AUTHOR:	DATE: 17/04/2008	X	WORKING	READER	DATE	CONTEXT:
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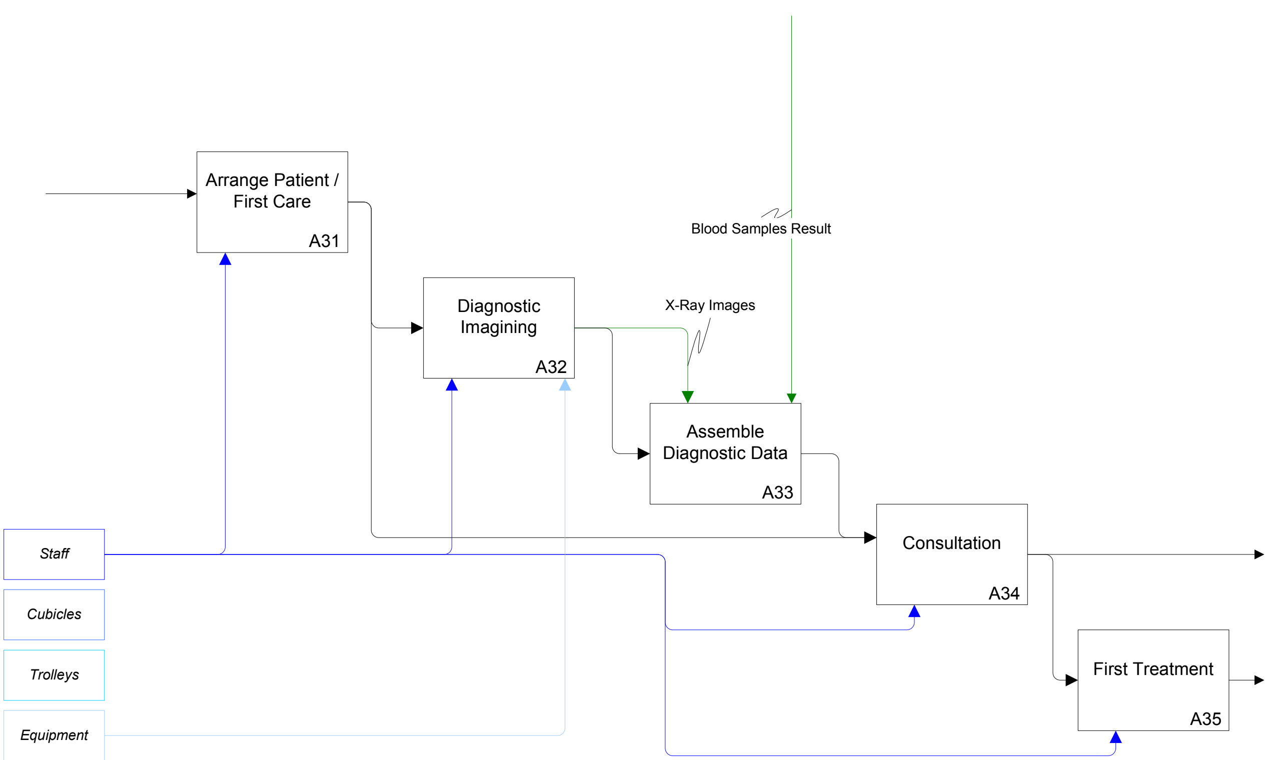
	NOTES:			PUBLICATION			



NODE: A3	TITLE: Quiet Room A2	NO.: 13

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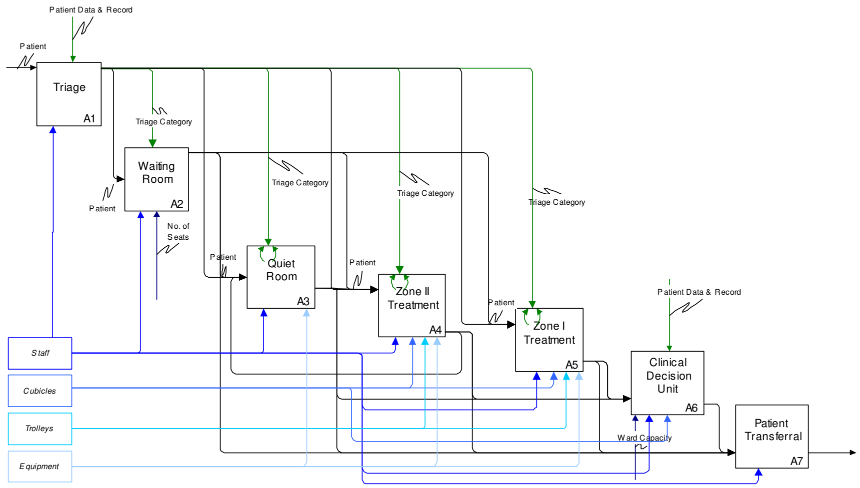
	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone II

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



NODE: A0	TITLE: Psychiatry Treatment A0	NO.: 13

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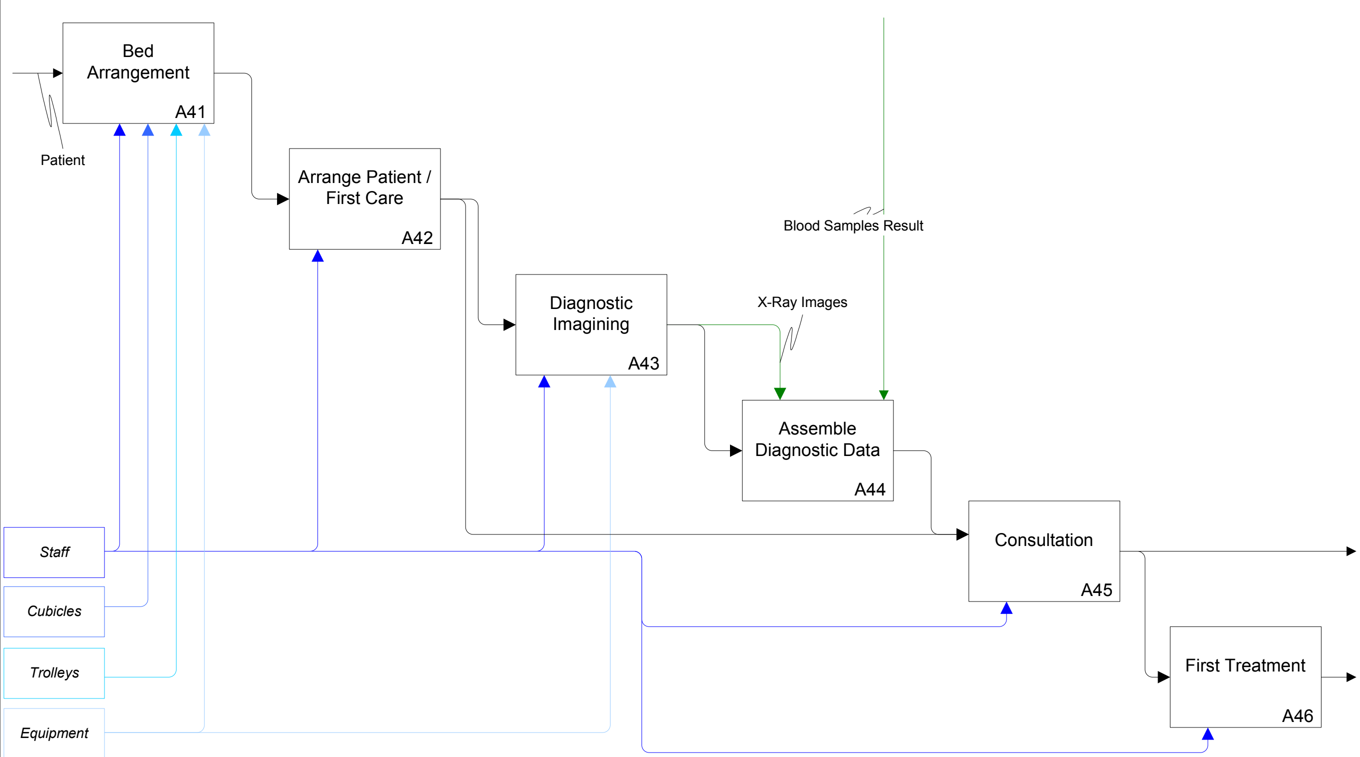
	NOTES:			PUBLICATION			



NODE: A4	TITLE: Zone II Treatment A4	NO.: 13

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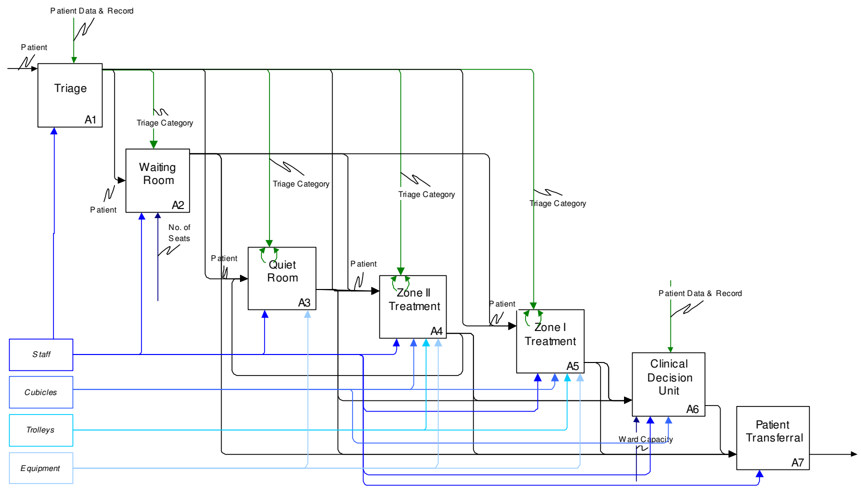
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone I

Zone I is reserved for patients with Chest Pain.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



NODE: A0	TITLE: Psychiatry Treatment A0	NO.: 13

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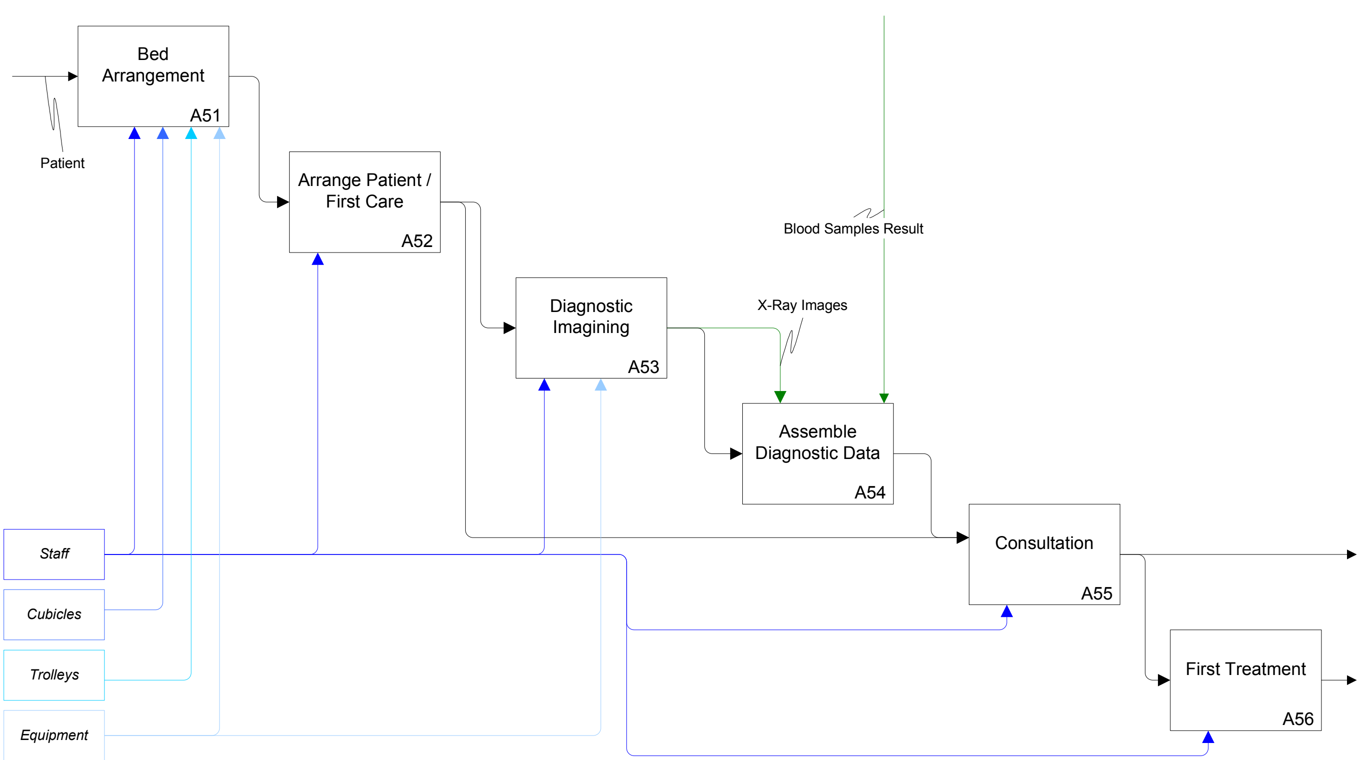
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			



NODE: A5	TITLE: Zone I Treatment A5	NO.: 13

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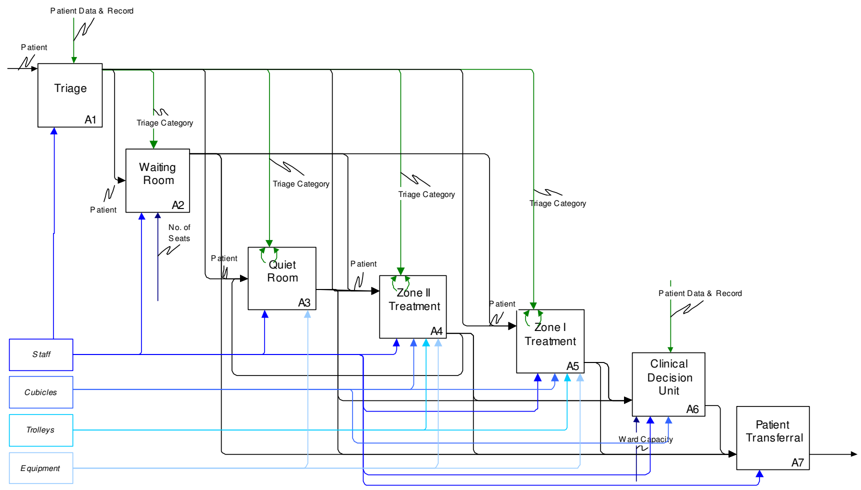
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Clinical Decision Unit

The Clinical Decision Unit (CDU) where the final decision is made whether to hospitalize the patients or sent them home. The decision is subject to patient condition and results from a considerable monitoring for the case status.



NODE: A0	TITLE: Psychiatry Treatment A0	NO.: 13

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ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
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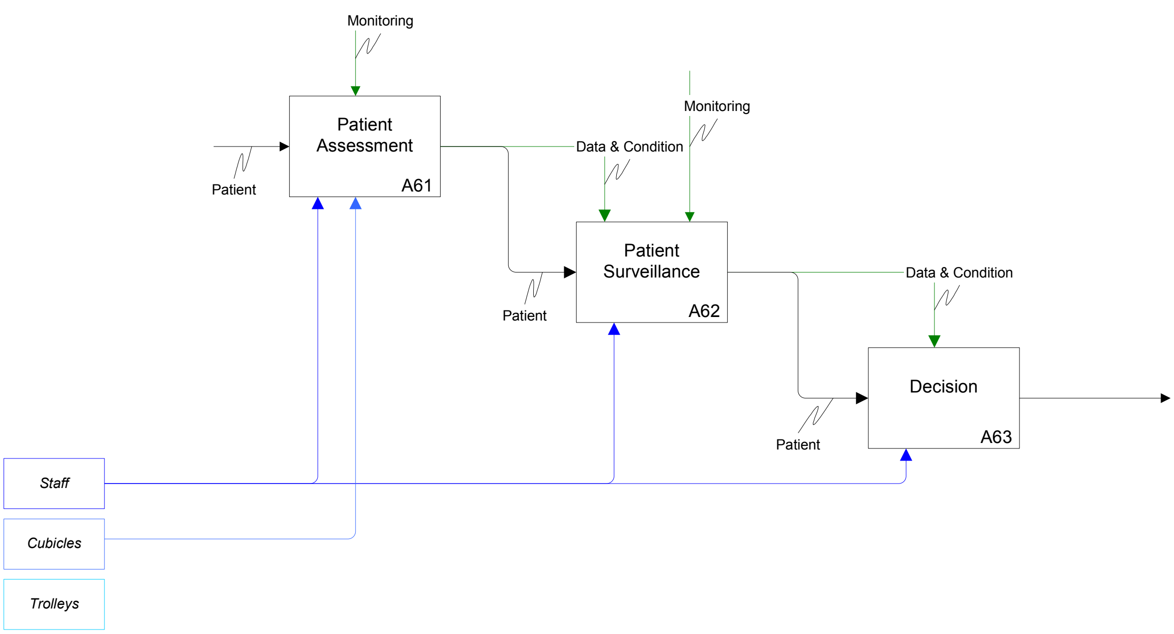
	NOTES:			PUBLICATION			

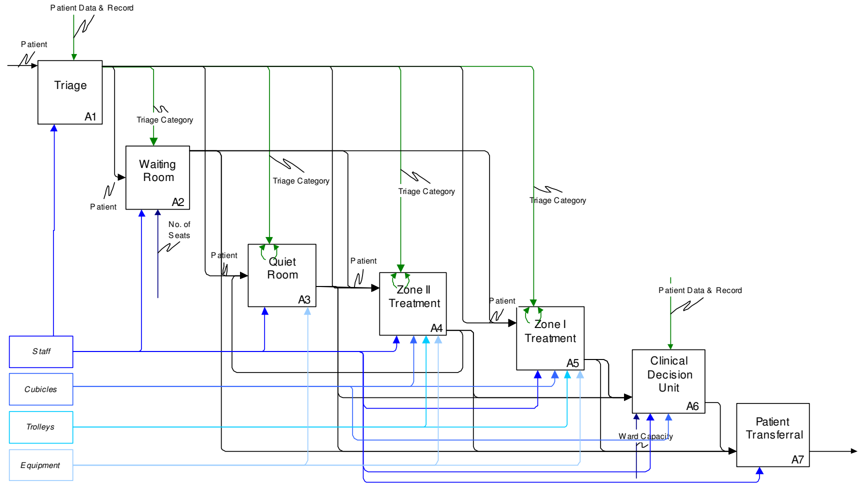


NODE: A6	TITLE: Clinical Decision Unit A6	NO.: 13

USED AT:	AUTHOR:	DATE: 17/04/2008	X	WORKING	READER	DATE	CONTEXT:
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Patient Transferal

Before any patient is ready to leave the ED, the patient record will be updated. The patient will either wait in his cubicle or moved to the corridor to free up a cubicle. Nurses usually look after the patient who are supposed to leave the hospital until they will be collected or driven home.



NODE: A0	TITLE: Psychiatry Treatment A0	NO.: 13

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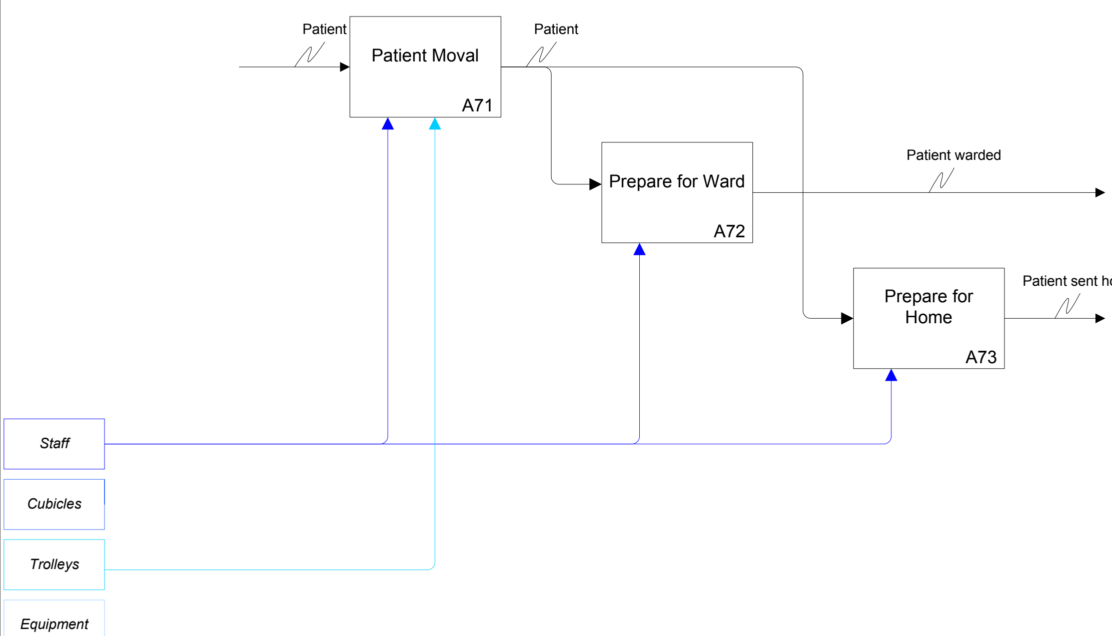

NODE: A7	TITLE: Patient Transferal A7	NO.: 13

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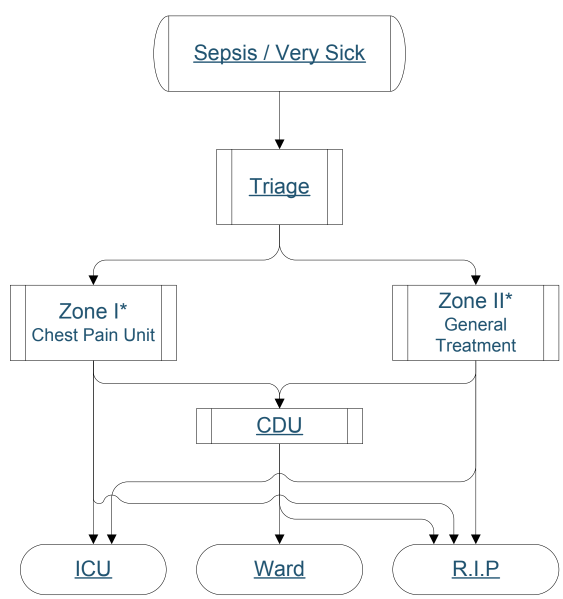
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			☐
				RECOMMENDED			
	NOTES:			PUBLICATION			

<u>Treatment for sepsis or very sick patients</u>

These patient show symptoms of organ failure and need immediate treatment. Triage as an instance might be skipped and the essential data will be obtained on the first sight of the patient. Usually patients are transferred to Zone I, while Zone II will only be used in case of capacity shortages of Zone I. X-Ray can be done by a portable device if necessary. Blood samples are not processed with special priorities. In sever cases the patients are passed through to the ICU immediately, while patients with a lower triage category are warded like usual patients. In the case of sepsis it might happen, that patients die in the ED, which encapsulates other procedures.



NODE: A-0	TITLE: Treatment of Sepsis / Very Sick A-0	NO.: 14

USED AT:	AUTHOR:	DATE:	17/04/2008	X	WORKING	READER	DATE	CONTEXT:
ED in SVUH	PROJECT: PM of ED@SVUH	REV.:	2.0		DRAFT			☐
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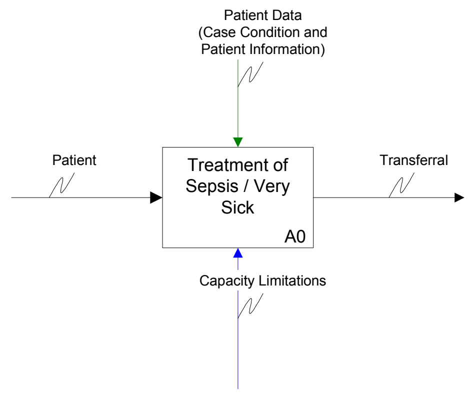

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USED AT:	AUTHOR:	DATE:	17/04/2008	X	WORKING	READER	DATE	CONTEXT:
ED in SVUH	PROJECT: PM of ED@SVUH	REV.:	2.0		DRAFT			■
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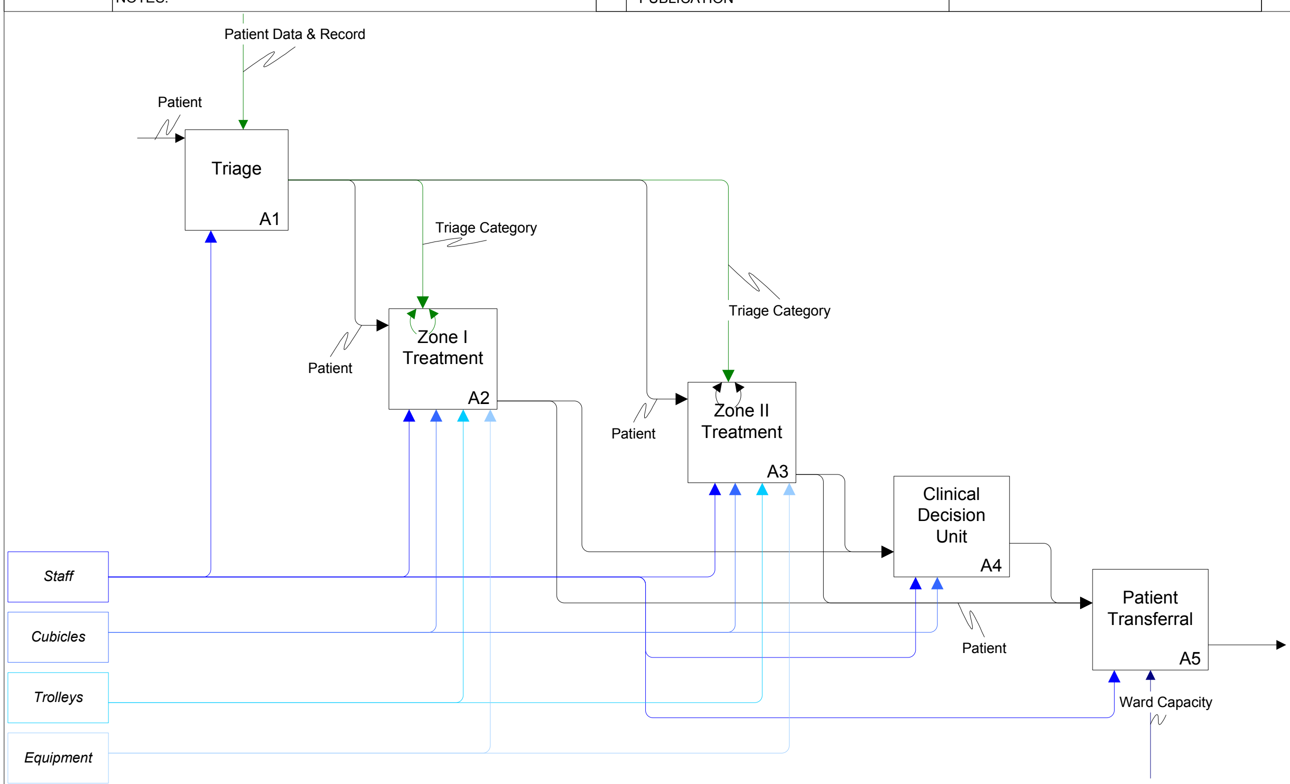

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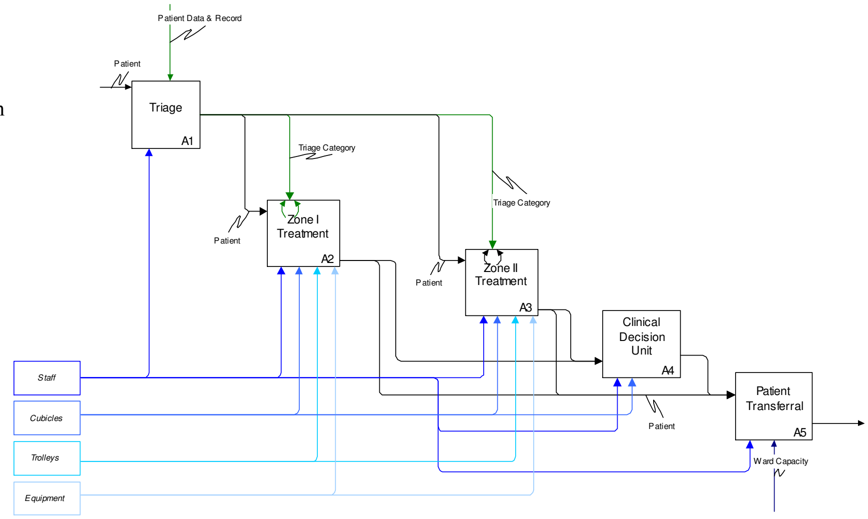
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Triage

The triage procedure for patients with organic failure is done by the triage team. Patients are usually sent to Zone I. The patient is assessed based on the accident and a patient record is made. The details obtained from the patient are then handed to the administrational staff. Blood samples are taken as soon as the patient is in a safe environment. The administrational staff is then arranging an appointment for X-Ray. All the findings and diagnostic results are stored in a patient record.



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ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
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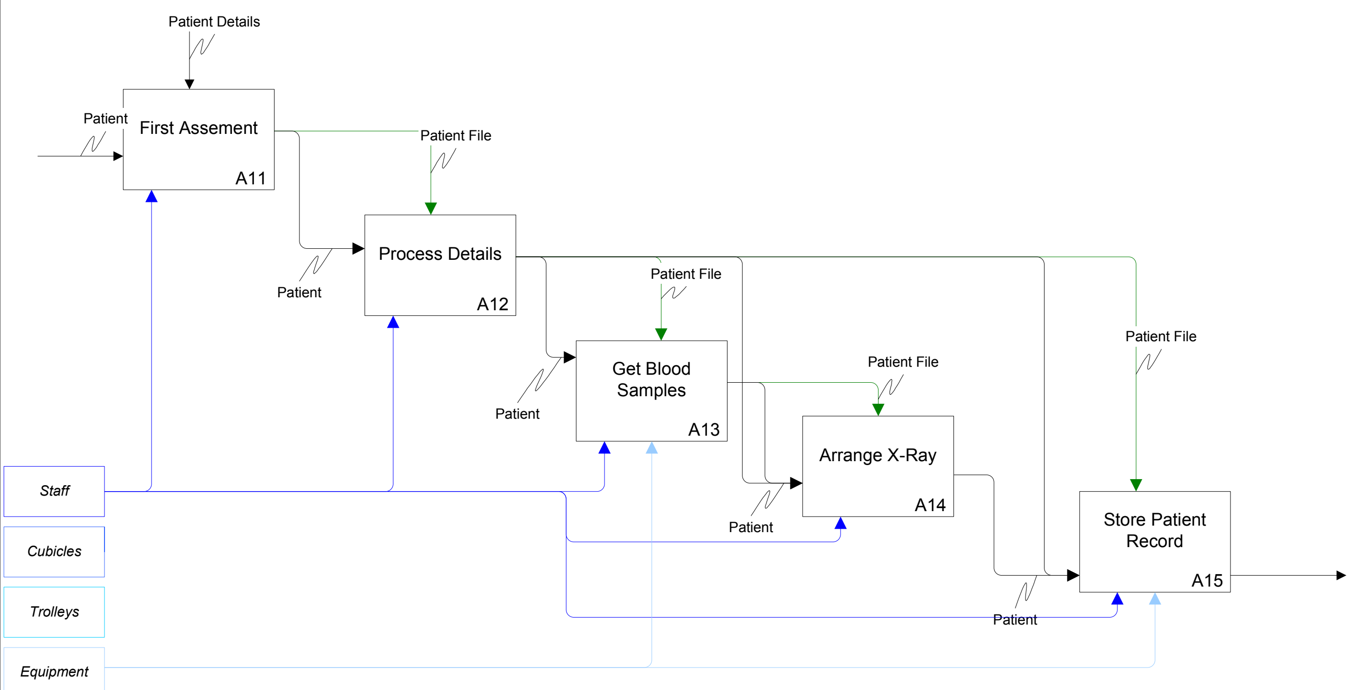

NODE: A1	TITLE: Triage A1	NO.: 14

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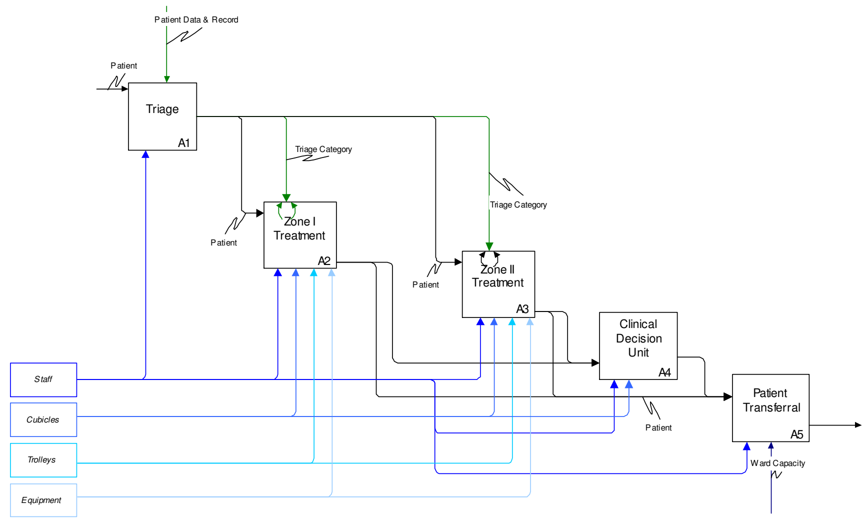
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone I

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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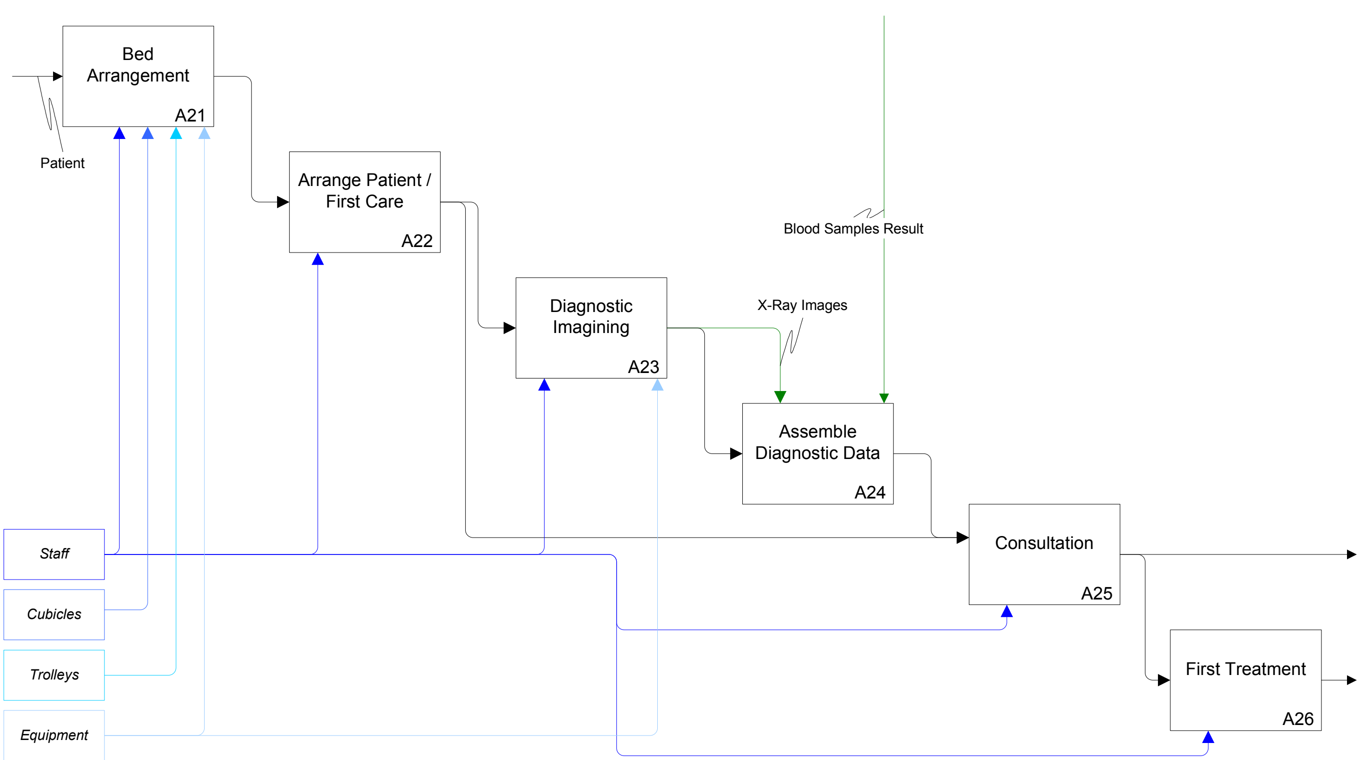


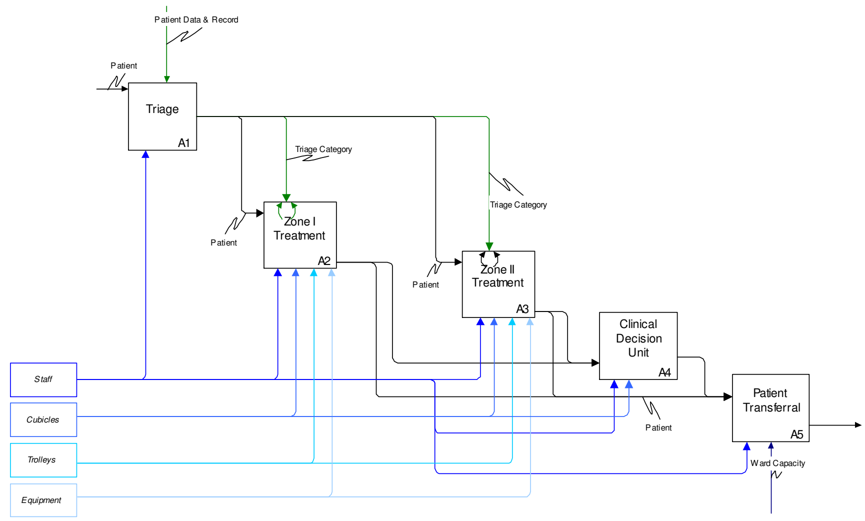
NODE: A2	TITLE: Zone I Treatment A2	NO.: 14

USED AT:	AUTHOR:	DATE: 17/04/2008	X	WORKING	READER	DATE	CONTEXT:
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Zone II

Those patients that would usually be placed in Zone I for special monitoring are placed in Zone II if Zone I is already fully occupied.

A bed or trolley is arranged and placed for the patient either in a cubicle (if available) or a free space of the corridor. Cubicles are equipped with monitoring devices. Swapping patients is an option for emergency cases.
As soon as the patient is placed in a bed, staff try to comfort the patient. If X-Ray is required, patient will be guided using a wheelchair or the entire bed (if needed). Patient file (record) will be updated with the new X-Ray image. A primary diagnosis is to be made based on the X-Ray images, however another opinion might be needed in complicated cases. Once the staff agreed the final diagnosis of the patient, they advise the patient on the required treatment and the care pathway needed in hospital.



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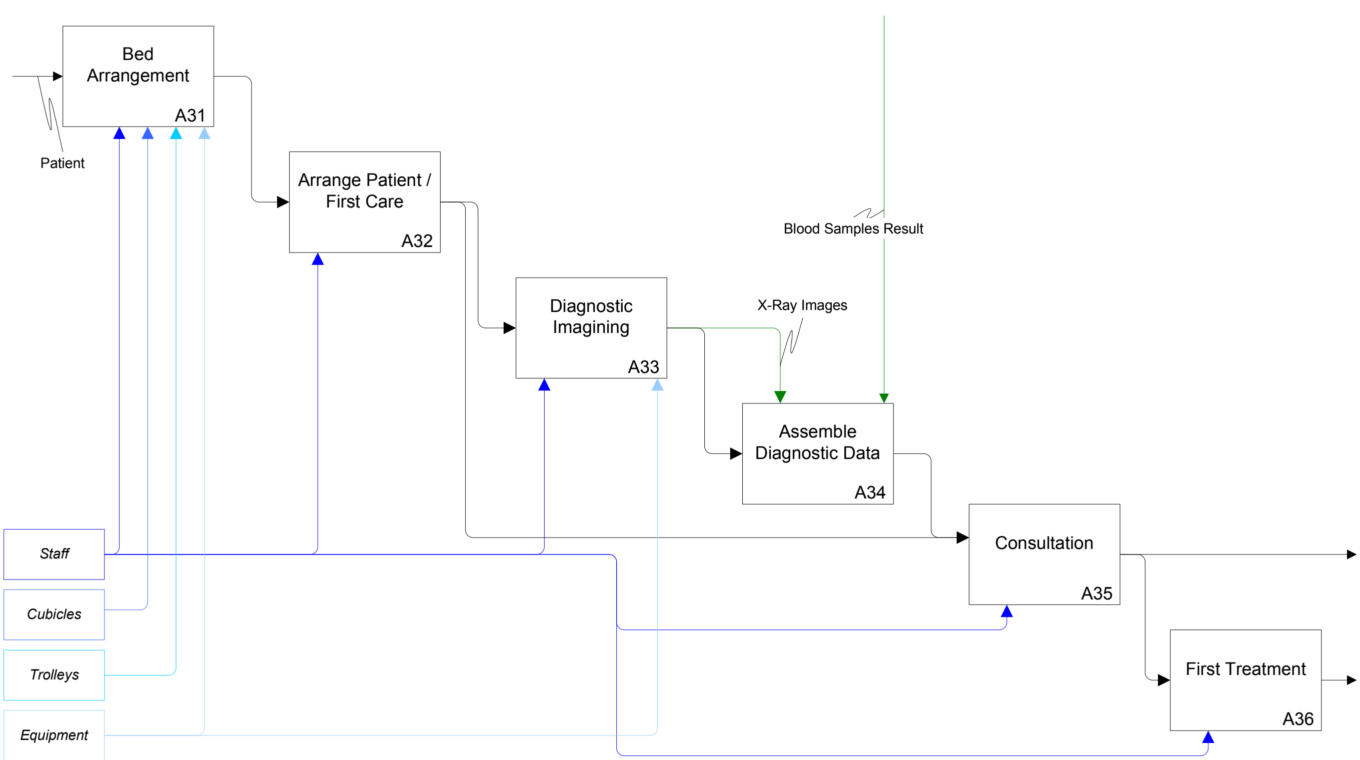
	NOTES:			PUBLICATION			



NODE: A3	TITLE: Zone II Treatment A3	NO.: 14

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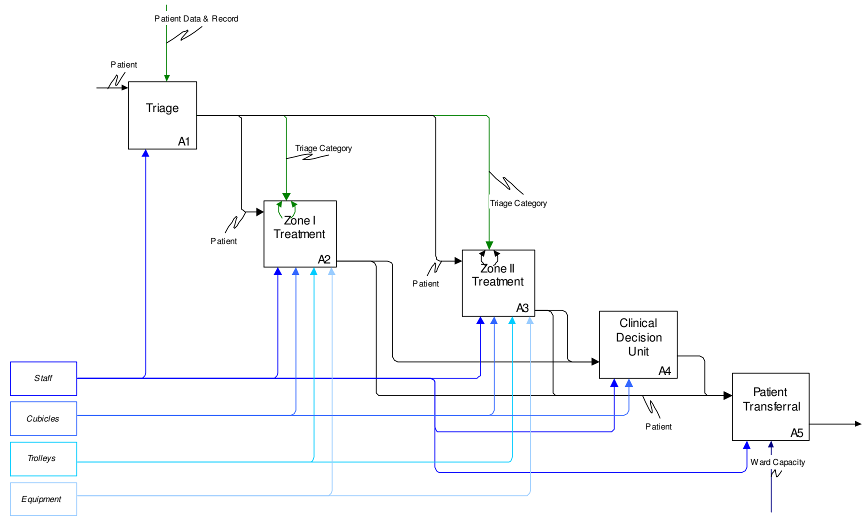
	NOTES:			PUBLICATION			

Clinical Decision Unit

The Clinical Decision Unit (CDU) where the final decision is made whether to hospitalize the patients or sent them home. The decision is subject to patient condition and results from a considerable monitoring for the case status.



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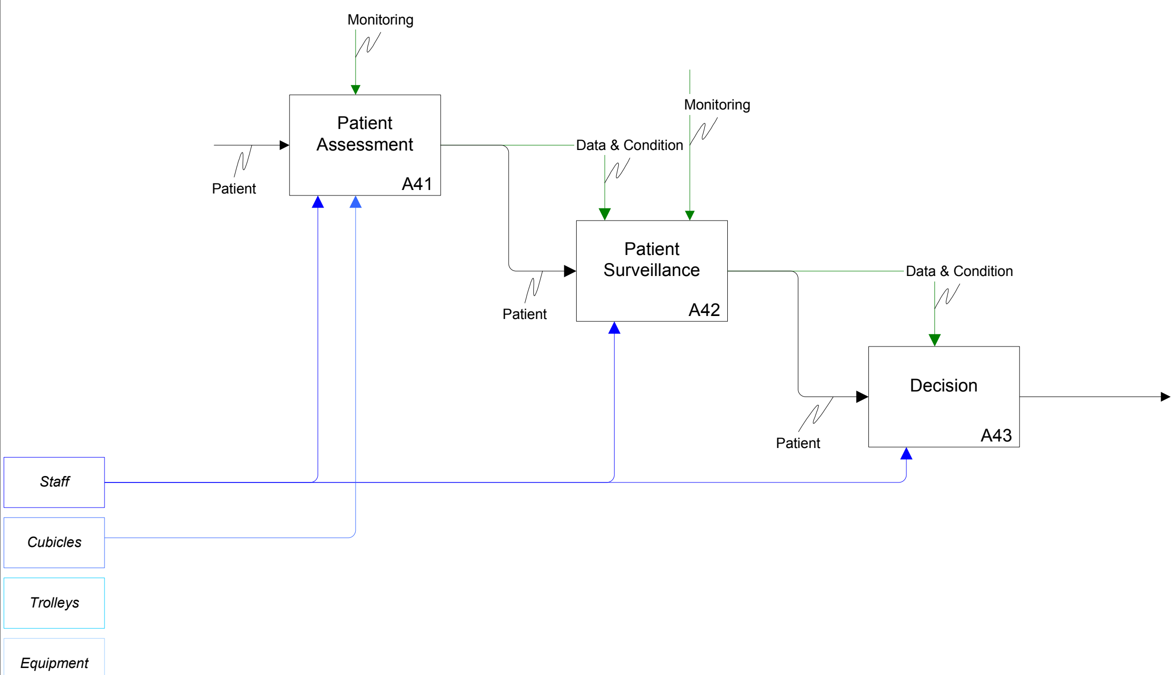

NODE: A4	TITLE: Clinical Decision Unit A4	NO.: 14

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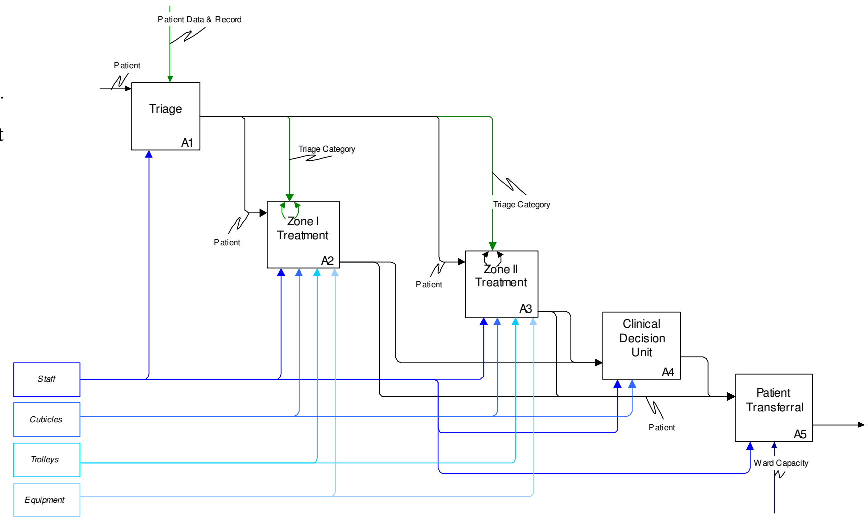
ED in SVUH	PROJECT: PM of ED@SVUH	REV.: 2.0		DRAFT			
				RECOMMENDED			
	NOTES:			PUBLICATION			

Patient Transferral

In case that the patient is in a severe condition, the patient will be transferred to the ICU immediately. Otherwise he will be assessed on his current condition.

Before any patient is ready to leave the ED, the patient record will be updated. The patient will either wait in his cubicle or moved to the corridor to free up a cubicle.

Unfortunately patients do die if their condition is too severe.



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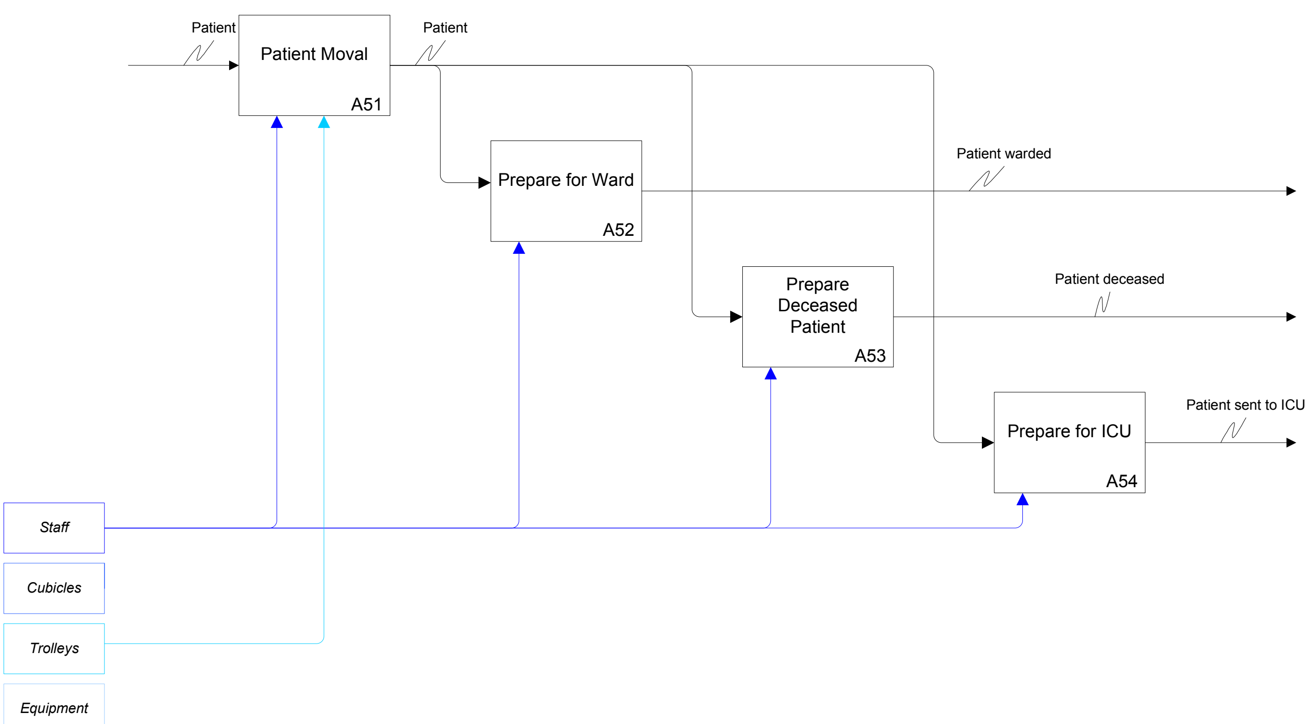

NODE: A5	TITLE: Patient Transferal A5	NO.: 14