FEDERAL UNIVERSITY OF PERNAMBUCO
POSTGRADUATE PROGRAM OF PRODUCTION ENGINEERING

PERNAMBUCO'S HEALTH SECTOR: ANALYSIS OF QUEUEING PROBLEMS AND AN ECONOMIC GROWTH MODEL

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Advisor: Fernando Menezes Campello de Souza, PhD.

RECIFE, June 3, 2013

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by

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A comissão examinadora, composta pelos professores abaixo, sob a presidência do(a) primeiro(a), considera a candidata **TAMIRES TAÍS BEZERRA ROCHA APROVADA.**

Recife, 04 de abril de 2013.

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Prof. MIGUEL ARCANJO DOS SANTOS JÚNIOR, Doutor (UFPE)

“The mind that opens to a new idea never returns to its original size”

Albert Einstein

Dedico esta dissertação a todos os Brasileiros que sofrem com os problemas das filas no sistema de saúde

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RESUMO

Esta dissertação apresenta um panorama do sistema de saúde brasileiro, com ênfase no caso do Estado de Pernambuco. A gestão de sistemas de saúde se manifesta sob a forma geral de longas filas de espera, que são analisados neste contexto, incluindo algumas abordagens que têm sido propostas e implementadas em Pernambuco, a fim de resolver o problema. Um modelo de crescimento econômico ótimo destacando o setor de saúde, e, em seguida, operando em conjunto, os setores de saúde e educação, é proposto. Os resultados do princípio do máximo de Pontryagin aplicado a este modelo mostram os benefícios mútuos para ambos os setores e os seus efeitos no bem-estar da sociedade. Um estudo de caso de filas de espera no Hospital da Restauração, em Recife, Pernambuco, é apresentado.

Palavra-chaves: Hospital da Restauração do Recife, Teoria das filas, Filas, Setor de Saúde, Suspensão Cirúrgicas, Modelo de Controle Ótimo

ABSTRACT

An overview of the Brazilian health care system is presented, with an emphasis in the Pernambuco state case. One central issue concerning health systems management manifests itself under the general form of long waiting lines, which are then here analyzed in this context, including some approaches that have been proposed and implemented in Pernambuco in order to tackle the problem. An optimal economic growth model highlighting the health sector, and then, operating jointly, the health and education sectors, is proposed. The results of the Pontryagin Maximum Principle applied to this model show the mutual benefits for both sectors and their effects in the community welfare. A case study of queueing systems in Hospital da Restauração (an emergency hospital) in Recife, Pernambuco, is presented.

Key-words: Hospital da Restauração do Recife, Queueing Theory, Queue, Waiting Lines, Health Sector, Surgery Suspensions, Optimal Control Model

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1 INTRODUCTION

Waiting lines are everywhere.

1.1 Prolegomena

How much time do we waste in lines per week? Waiting lines is all around us and it seems we cannot escape from them. Queues involve high costs not easily perceived, related with the clients waiting for service, decreased clients satisfaction, salaries paid to employees while they wait for service from other server and costs incurred by society.

To reduce the queues, the administrator should decide that a given percentage of entry level clients may not be allowed to wait for service longer than a certain time. Or he may choose to minimize the total amount of money spent on the operation. According to Siciliani *et al.* (2007), there is a level of waiting times that minimizes the total costs. Above this level, higher waiting times increase establishment costs. The research of the authors defined that the level of waiting times which minimizes total costs in hospitals is always below ten days.

The importance of studying queues is more than just determining the logistic structure. Queueing theory can improve the operation of the system through a balance of the processes to eliminate bottlenecks. The main objective is to reduce the uncertainty about the arrival rate and the length of service. The impact of this variables in the services performance can be estimated and the supply can be planned (controlled) based on the estimation, so the system can be optimized. Hospital queues are not much studied in Brazil yet.

The Health Ministry of Brazil created the Quali-SUS to reduce the queues and the time spent on them: a system that attends according to the severity, not according to the order of arrival. After the reception by a team of professionals, the patient goes to a screening where his risk is measured. The classification is **red** (and the patient has to be attended immediately), **yellow** (the patient can waits 15 minutes at maximum), **green** (thirteen minutes) and **blue** (the patient can wait until three hours). For that structure to work, the emergency of the 'Hospital da Restauração' of Recife had to be reformulated with different entries for different patients. The Hospital da Restauração in Recife is the largest unit of the Pernambuco's Public Health System with the more complex emergency and trauma departments in the North/Northeast of Brazil.

1.2 Justification

The queueing in public services, so-called free, are consequences of the inevitable excess of demand for "free service". The population can not notice the price paid to face these queues: time and taxes. The waiting line in health sector is a way of prioritization, treating the urgent cases while deterring the patients that will have less benefits. So, as expected, the main bottleneck is in the elective treatments. Elective procedure is the one which is scheduled in advance because it does not involve a medical emergency. Although non-emergency, if not appropriately answered, these patients can have a health worsened what can lead them to death.

Any queue related to the health service will affect its performance. Not only the medical queues, but any queues that can reduce the patience, attention or mood of doctors and nurses. For example, the parking lot queues, the elevator queues and the restaurant queues.

Historically, the Brazilian public health services have been constructed based on the supply. More than an improvement in the chain it is necessary a good administration of the existent resources. In order to improve performance of the system, with better management of the resources, the dynamic of health queues and all queues involved somehow with the health sector need to be understood, so administrators can match their objectives with the specific issue that waste time. This work analyses this dynamic proposing suggestion for optimizing the hospital resources.

1.3 Objectives

1.3.1 General Objective

The aim of this work is to analyse the network queueing system in the Pernambuco's Health Sector and to establish conditions to optimize this system.

1.3.2 Specific Objectives:

1. To analyse the institutional arrangement of the Pernambuco's Health System;
2. To stablish connections between the institutional map in the Pernambuco's Health System and the queues;
3. To analyse queues in the restaurant, elevators and the parking lot at 'Hospital da Restauração' of Recife;
4. To elaborate and develop an economic growth model for the Health and Education Systems based on the model by Stamford da Silva and Campello de Souza (2008);
5. To suggest actions to reduce the queue problems analysed.

1.4 Methodology

The scientific method adopted in the first part of the study was the exploratory analysis with the goal of acquiring an indicator of the dynamics of the health sector at the Hospital da Restauração. The basic steps of the procedure: Planning and development of the research questionnaires, data collection, preview analysis of the data, literature review, a priori knowledge to explain the research results.

For the second part of the analysis, the optimal control model, it was adopted the hypothetical-deductive analysis which is a method of attempts and errors in which the absolutely right and demonstrable knowledge is not reached.

1.5 Introductory Note

This work started with the case study of the restaurant of the 'Hospital da Restauração'. In September of 2011, the group of students in the Probabilistic System Class went to the hospital to do the research among the users of the restaurant – hospital staff and companions.

In the first part of the research the students distributed the survey among the employees to measure their perception about the waiting times in the queue. In the second part of the research, the students measured the time in the queue.

After the restaurant queue research, we expected to have access to the database of patients flow information. After few months, we did not have access to this database because of problems with the staff responsible for its supply. That is why it was decided to develop an optimal control model for the health sector.

1.6 Structure of the Dissertation

The work is structured in six chapters, presenting in the first one (Introduction) a general introduction with the contextualization of the problem, the objectives of the dissertation, justification and methodology used.

The Chapter 2 highlights problems and the potentiality of the relationship between agents in the health system, specially in Pernambuco.

Chapter 3 explains the queueing theory and makes a literature review of other works done in this theme.

Chapter 4 analyses how the government is investing to reduce the queues. There are also management action to solve general health queues problems.

The Chapter 5 studies the case of the Hospital da Restauração in Recife presenting the hospital characteristics and then the restaurant queue research with its results.

Chapter 6 shows the optimal control model starting with an explanation about the dynamic systems, the model and its results.

Finally, chapter 7 presents the conclusions and comments of the whole work.

2 THE HEALTH SECTOR

> *"It should be noted that the subject is the medical-care industry, not health. The causal factors in health are many, and the provision of medical care is only one. Particularly at low levels of income, other commodities such as nutrition, shelter, clothing, and sanitation may be much more significant."*
>
> (Arrow, 1963. p. 931)

2.1 The Brazilian Health System

UP to 70% of the expenses in the Brazilian health sector is concentrated in the public and private hospitals. In Europe and North America this relationship is 40% to 50%. In Brazil, any symptom is a reason to go to the hospital. But a lot of these symptoms could be treated in the ambulatory or in the 'Primary Health Care Service' (Serviço de Atenção Básica) with minor costs. This is the argument of the La Forgia · Couttolenc (2008). In an interview for Valor Economico newspaper, Couttolenc said everyone complains about the lack of investments in health and in hospitals, but no one says that 30%, at least, of the hospitalizations should not exist.

The Primary Health Care is the first level of attention in the health system. Every municipality must have it with quality and adequate for its population. It is the set of actions and minimum strategies needed to an appropriate care of the local health problems. With the evolution of the medicine, some procedures that used to require the confinement of the patient is now done in the ambulatory. Besides, the advance of the Primary Health Care and the Community Health Agent are responsible for less hospital treatments in the last few years. Although the technological advance and the fact that the Brazilian Health System was created to guarantee the distribution of health assistance for all population, the constitution definitions did not create capacity for the SUS hospitals to attend all population, a situation worsened by the demographic growth. It demands improvement of the attending structure. And it seems there is a disconnection between expenditure and results. Then, it is not only increasing the investment in health, but increasing the guarantee of the investment in every instance and requiring results.

The socioeconomic conditions affect the person's health and consequently the population's health. A person can become ill or suffer from a motorcycle accident. In each case he is sick. Awhile the first situation can be anticipated, the second one is purely randomly and the health system deal with both. Many middle and high income Brazilians covered by private insurance use the SUS occasionally, particularly by high-complexity services or for services not covered by private insurers (La Forgia ˙ Couttolenc, 2008). The health quality and life expectancy are related to the productivity capacity of a person. The health situation modifies the productive capacity of a country. And that is why governments are committed to the health sector.

For the analysis of the public hospitals performance, Gonçalves *et al.* (2007) applied the Data Envelopment Analysis. The authors utilized the Constant Returns to Scale model to generate scores and evaluate efficiency of the health unities, ranking them according to the result. Since the tool showed efficiency to availability of the performance of hospitals, Freitas (2002) applied the same method to analyse the Recife Health Complex Facilities (the so called Recife Medical Center, Pólo Médico do Recife). He showed there is a reduced number of efficient hospitals when it is imposed constant returns to scale. The health system has a problem of sustainability, represented by a variety of factors. The most important is the excessive utilization of the medical procedures. Hospitals blame health insurance because they do not adjust the procedures prices and the health insurance blame the hospitals about unnecessary procedures (Freitas, 2002).

2.1.1 The Health Unique System (SUS)

A health service creates positive externalities because the individual health provides benefits beyond the individual. A public good is a non-excludable and non-rival good. It means that the usage of the good does not reduce the availability to others and once is paid, it is not possible to prevent people who have not paid for it from having access to the use of the service or good. The public health system does not drive for profit. Associated with this, the lack of investment to the basic infrastructure has serious consequences on its service quality.

The Health Unique System was created by constitutional dispositions in 1988 and implemented under the Health Ministry in 1991 by the law. The Brazilian Health Unique System is one of the largest public Health System of the world, and it is the only one to guarantee integral and completely free assistance for all population, including HIV patients, chronic renal patients and cancer patients (FNS, n.d.). The Health Unique System was created with the goal of changing the inequality of distribution in the population health assistance. For that reason, the service is available for any citizen and it is forbidden any charging under any context.

The SUS is funded by the duties paid by population. The democratization of the relevant information implies that the population is aware of its rights and risks to the health. But the universality of this public health system takes an exclusionary connotation because of the conjugated effect of two mechanisms: the migration of the people with middle and high income to the private system; and the rationing of the public system supply (Ribeiro, 2009). The health system before SUS had not the equality objective despite its robustness, so it is huge the importance of guaranteeing the access to the health service because it is aligned with the constitution, which does not mean that the system is efficient.

The Health Unique System is a responsibility of the federal, state and municipal governments. The federal resources correspond to 70% of the total, and has been transferred to state and municipal district by direct transference of the National Health Fund (Fundo Nacional de Saúde, FNS) which operationalizes the financing of determined actions. The federal government is still responsible for most of the Health Unique System financing, but the participation of municipal district has been growing up. Independently which government level made the payment of a service, the SUS utilizes the same Information System for ambulatory service (Ambulatory Information System) and for hospital (Hospital Information System). Also for the payment of the service, the public system utilizes a unique “price sheet” defined by the Ministry of Health. The trend is to decentralize the system, so the municipalities can assume the responsibility for delivering the service.

The Ministry of Health defines the National Health Policies and Priorities, but states and municipalities are autonomous. There is a decentralization focused on the empowerment of local governments, not on the program managers. One level of government has no influence in another level of government. Neither from federal to municipal or state nor even in the same level (state to state, for example). To the regionalization of the medium and high complexity care and to define the role of the state health secretariat in this regionalized delivery system, was approved the Health Care Operational Norms (Normas Operacionais de Assistencia à Saúde, NOAS) in 2001. The main goal of the NOAS is to promote a better equity in the resource allocations and in the access of the population to health actions and services for all levels of complexity.

According to La Forgia ˙ Couttolenc (2008) the SUS is based on a complex system of payment mechanisms and fund transfers such as:

- The Authorization for Hospitalization System (Autorização de Internação Hospitalar, AIH) and the Hospital Information System (Sistema de Informação Hospitalar, SIH) consist of federal payments from the Health Ministry (Ministério da Saúde, MS) for inpatient care;
- The Ambulatory Care Information System (Sistema de Informação Ambulatorial, SIA) consists of federal payments for outpatient and emergency services;
- Federal transfers to state and municipal health secretariats relating to hospital care. These are the payments for the medium and high-complexity care.
- Additional federal payments for university and high-complexity facilities and for facilities providing specialized care (as cardiac surgery and transplants) and emergency care.

2.2 The Pernambuco's Health System

2.2.1 The Agents and the Institutional Arrangements

The user pays the physician directly or through health insurance/hospitals. The physician pays the hospital for the usage of its equipments. The hospital pays the physician's salary. And so on.

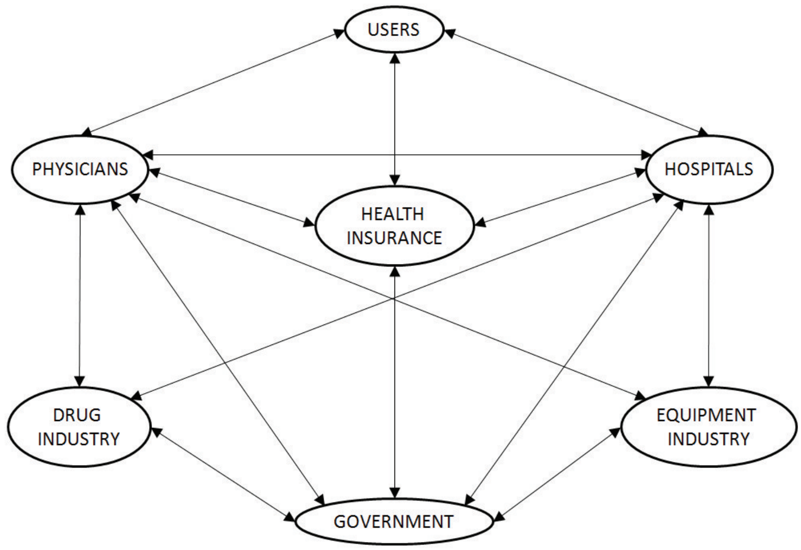

Figure 2.1: The Institutional Arrangement in the Brazilian Health Sector.

The figure 2.1 shows the strong interaction between these agents in the health system. It is not possible to separate the health system into individual parts to analyse it, the system must be optimized as one. According to Porter ˙ Teisberg (2007) this interaction is a zero sum competition. A zero sum game is a mathematical representation of a situation in which a player's gain (or loss) of utility is balanced by the losses (or gains) of the utility of the other participants.

> *Physicians are pressured to "improve productivity" by skimping on time spent with patients. Physicians "win" by cutting better deals with their hospitals or by setting up their own profit-making venture. Hospitals "win" by merging into groups to gain more bargaining clout on rates or by signing up more physician groups to guarantee referrals. Health insurances "win" by restricting services and muscling physicians to accept lower pay. In ways such as these, each player in the*

> *system gains not by increasing value for the patient but by taking value away from someone else. (Porter & Teisberg, 2007)*

In the end, all players lose including the patient. Improving their own utility, each agent does not center the care in the patient and the health efficiency is not maximized. Porter suggests a competition over better results – better health outcomes per dollar spent. A positive-sum competition can create value, enhancing the quality of the services. This section briefly describes each one of these agents in the Pernambuco's Health System.

The Government

The Brazilian government acts as an economic policymaker and as one of the financial agents in the health system. To assure a minimum of coherency in the necessary actions in the basic health, the transfer of federal resources is per capita and directed to specific programs and actions. To reduce the regional inequalities, the states with lower per capita resources had an increasing in the amount of money transferred. The government pays physicians, hospitals and the pharmacy industry to freely distribute medicine for the population.

The Government of Pernambuco, aligned with a national strategy, defined as a goal to increase the supply of beds in the public health sector and unburden the main emergencies. For that, three new units were implemented in the Metropolitan Region of Recife with health private sector administration: the govern maintains the ownership of the hospital and the administration is transferred for a private institution. The state of Pernambuco implemented this model in the 22 Emergency Units (UPAs) and in the three hospitals of non-spontaneous demand. The social organization which rented the UPAs administration are in fact private organizations that received public investment to offer free health treatment. The social organization choose through public selection to manage the three hospitals was the Institute of Integral Medicine (IMIP).

The Hospital Complex

One of the institutional guideline of SUS is the ranking of priority for the health service. This prioritization organises the patients flows into three ascendent levels of complexity:

Level I - Low complexity procedures. Ambulatories, Family Health Unity (USF) and Health Centres/Basic Health Units (UBS).

Level II - Ambulatories with specialties (Polyclinics) and Emergency Units (UPAs).

Level III - Reference hospitals with procedures of medium and high complexity.

There are five main public hospitals in the Metropolitan Region of Recife (RMR):

The **Hospital da Restauraffão** (HR) is the biggest unit of Pernambuco public health system. It is a reference in accidents and complex procedures – burnings and neurosurgery. The hospital has one of the largest Burning Treatment Center (CTQ-HR)of Brazil and it is a reference in Toxicologic Assistance Center (CEATOX-HR) in the state of Pernambuco in exogenous intoxication and poisonous. Since 2005 the HR is a teaching hospital and it has an important role as a health training center: they have the best and most experienced professionals in various categories.

The **Hospital Geral Otávio de Freitas** (HGOF)serves clinical cases of the southeast of Recife, in Jaboatão neighbourhood. Reference in psychiatric and traumatology-orthopedics urgencies. The hospital is also reference in respiratory diseases, specially tuberculosis, and in medical clinic, urology, general surgery and paediatrics. It is the only hospital in Pernambuco that treats multi-drugs resistant tuberculosis patients.

The **Hospital Getúlio Vargas** (HGV) is placed in the west part of Recife. Reference in traumas, it is certified as a teaching hospital since 2004 and offers residence in various specialties, highlights for surgeries in the hand, in the digestive system and in the spinal cord. The HGV was the first public hospital of North-northeast to offer videolaparoscopy, done trough a microcamera.

The **Hospital Barão de Lucena** is reference in maternal and high complexity child health service. They attend around four thousand patients per month in the two emergency specialties – obstetric and pediatric.

The **Hospital Agamenon Magalhães** (HAM) is licensed in cardiology as a high complexity reference hospital. There is an Intensive Care Unit (ICU) just for the post operation of cardiology surgeries, with four beds. Another reference specialty is the high risk maternity. There is a floor to the ICU for adults and neonatal. There is also a Intermediate Care Unit for neonatal. The HAM is the only public emergency in Pernambuco in otorhinolaryngology.

Pernambuco has two university hospitals. The university *Hospital Oswaldo Cruz* is the hospital of the Faculty of Medical Sciences at the University of Pernambuco (UPE) and the *Hospital das Clˆnicas* (HC) is the hospital of the Federal University of Pernambuco (UFPE). Both have important function in the training, qualification and development of medicine students.

There are three hospitals in the Referenced Attendance Policy according to a protocol. It means they receive patients forwarded by the public health system – Mobile Emergency Care Services (SAMU), Fire Department and Regulation of Beds Center. They are known as the non-spontaneous hospitals.

The *Hospital Miguel Arraes de Alencar* is a north metropolitan hospital launched in 2009. It is the first major trauma hospital constructed in the Metropolitan Region of Recife (RMR) since Hospital da Restauração, forty years before. The unit is managed by IMIP. It is pioneer in the integrated attendance.

The *Hospital Dom Helder Camara* was founded in 2010 and it is the integrated attendance hospital in the south metropolitan region of Recife. The hospital stands out because of its cardiology center, a specialty with high demand in the health system.

And the *Hospital Pelópidas Silveira* was inaugurated in 2011 and is one of the most modern and specialized hospitals of the country, considering the private hospitals. It is the first neuro cardio hospital of the Public Health System (SUS). In urgent and emergency care in clinic surgeries, the hospital serves patients with myocardial infarction or other heart diseases, aneurysm, cerebrovascular accident (stroke) and brain tumors, among others, all forwarded by the public health system. It relieves the HR and HGV demand in neurology and neurosurgery; and the HAM and the Dom Helder Camara Hospital demand in cardiology treatments. The hospital offers specialized tests and works 24 hours in the west metropolitan region of the state.

After the reception in these hospitals, the patient is classified to the service according to health parameters and not according to the order of arrive. The process classifies, according to a protocol, the symptoms described by the patient, selecting patients who need urgent care to guarantee the severe cases to have priority in the service. The screening reception is made by colour: red for immediate assistance, yellow for urgent, green for less urgent and blue for not urgent.

The Emergency Units (UPAs) were launched in 2009 and according to Health Ministry they can properly solve at least 70% of the care provided in hospitals. These units are a part of the pre-hospital fixed system with strategic location for setting up the attention to the urgency with Reception and Risk Classification (ACCR) according to the National Policy for the Emergency (2003).

This work could not be done without the support of the SAMU. Some time ago, when the ambulances were sent to the treatment, they could drive for hours before find a bed in a hospital to leave the patient. By this time when SAMU goes to the place to attend, it knows exactly to where the patient must be taken. The SAMU 192 service have a multi-professional team in the Medical Regulation Centers with more than 500 professionals. Since December of 2012, when Recife received more seven ambulance, the SAMU fleet is 24 ambulances – with 18 for first aids and the other 6 for advanced attendance (ICU); three motocycles and one car for fast support; and two helicopters in convention with the Federal Highway Police and the State Government. Per month, the SAMU in Recife performs more than four thousands of treatments (Pernambuco, 2012).

After dialing 192, the citizen is calling to a regulation center with health professionals and physicians trained to give first care help. The call is took by a technical and

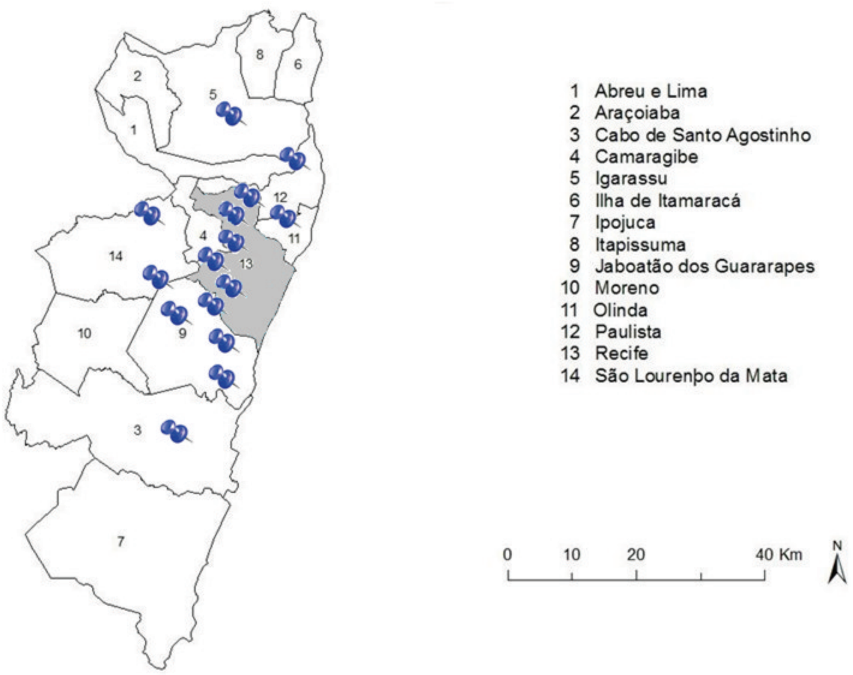

Figure 2.2: Localization of the UPAs in the Metropolitan Region of Recife - Pernambuco.

transferred to the physician in charge. This last professional makes the diagnosis of the situation and orientates the patient or the person who called about the first actions. The professional evaluates the best procedure to be made: to ask the person to look for a health centre; to send an ambulance to support basic care for local attendance, with nursery assistant and a professional for the first aid; or, according to the severity of the case, to send an Intensive Care Unit (ICU) with physician and nurse. With the power of a sanitary authority, the regulator physician looks for the hospital with empty beds next to the call to proceed with the treatment. The whole procedure is a queue.

The Pharmaceutical Industry

The Research and Development (R˙ D) area is an expansive investment and requires highly qualified people, so there is a barrier to new market entry. In Brazil, it is necessary to implement public policies to encourage the national medicine production, including the production through native plants. The R˙ D investments in Brazil are low compared with other countries. There was significantly participation of the generic medicines in the last years, which relatively reduced the participation of the innovative medicines in the market[1]. These aspects combined with the low integration of the supply chain in the sector and the concentration of the businesses in multinational laboratories, characterized the last few years in Brazil. Because of this, since 1999 the National Health Surveillance Agency (ANVISA) is concerned about increasing the sanitary patterns in the national production and improving the conditions to exportation. ANVISA is controlling the quality of the products in the sector.

Inside of the pharmaceutical industry there is a marketing industry and the sales representatives are important intermediates between physicians and drugs companies. Nowadays, most patients go to the doctor's office only because of the medicine prescription. Since the time of physicians is short, the appointment can be resumed in prescription of exams and medicines, sometimes unnecessary, to attend the necessity of a consumerism culture. The users, on the other hand, have been using the internet information to self-medicate. Barros (1983) believes that the labelling of medical products is one of the mechanisms to increase sales, facilitating or encouraging self-medication. The author highlights the "overmedication phenomenon": when the use of medicines to treat diseases, which often have only palliative solution, becomes a common-place. The medicine is commercialized.

The price elasticity of the demand shows the responsiveness of the quantity demanded of a good or service to a change in its price. When the demand of a good is relatively inelastic, it means that changes in the price have small effect on the demanded quantity of a good. Medicine products are price inelastic. When people are sick, they need to use the medicine to get better and since there is no direct substitute, they are vulnerable to the price change. It is only different for lower-income population who does not have money to buy the medicine and only use the ones free distributed by government.

Brazil has favorable conditions to become a pharmaceutical industry advanced research pole. And its high bio-diversity increases the potential of the country to attracts investments. There is a Pharmaco-chemical Complex been constructed in Goiana, North of Pernambuco. The Brazilian Blood Derivatives and Biotechnology Company (Hemobrás), a Health Ministry Industry, intends to make Brazil auto-sufficient in the blood deriva-

[1] The generic medicines are produced after the expiration or waiver of patents and has the description of the chemical composition on the package, with no trademark

tives sector. This will provide more autonomy to Brazil concerning the health products, as medicines. It is a complex supply chain and the expectation is that other economical segments with technological basis establish themselves in the Complex to provide input to the production line. The factory is a process of technological transference from France and it will save R\$800 millions annually to Brazil with a capacity of processing of 500,000 liters of plasma, the raw material of blood products. Hemobrás has a strategic importance being the largest factory of blood products in the Latin America and it should initiate its production in 2014.

The Industry of Medical and Hospital Equipments

The Industrial Revolution started in the 18th century in United Kingdom and then Europe, United States, Japan to the world. It was a period of lots of changes (in transport, agriculture, mining, etc) but the special one was the substitution of the manual manpower and the animal traction in industry towards machine manufacturing. Thereat started an influx of population from the countryside into towns and cities.

This is the era of the Revolution in Medical and Hospital Equipments Industry. The physician are being trained to deal with machines, to read their results and to use the technology to support the diagnosis. It is a good advance since the physicians can diagnosis and even perform **surgeries** at distance. But it can be bad, because if the hospital has equipments out of calibration, the physicians will incorrectly diagnosis the patient. Physicians are almost completely dependent on the technology. The hospital cannot measure how money is wasted in bad maintenance of equipments. It creates a queue in the hospitals to use electronic medical devices to diagnosis tests and can even originate serious problems for misdiagnosis.

The equipment industry is the main responsible for the technology evolution in the health system. As technology increases in the health sector, prices rise, contrary to the traditional economic dynamic (Lopez, 2007). It happens because in the health system, the value is not made by the own product but by the added value of the product for the consumers – their health recovered. This is true for hospital equipments technology (high complexity treatments), but taking into consideration the tools for home care, there is a price reduction in this market. It is the case of blood pressure measurement and the first-aid machines. There are phone applications also, for people to track their personal welfare (diary exercises and nutrition diet, for example) and to prevent visit to doctor's office.

The Health Professionals — The Physicians

According to the Secretariat of Health Surveillance (SVS), in the 30s, the infectious and parasitic diseases accounted for approximately 46% of deaths in the capitals of the country. In 2003 it was found that these conditions corresponded to only 5% of the deaths in Brazil. Circulatory diseases have the highest mortality rate. Cerebrovascular Accident (CVA), commonly known as *stroke*, had an incidence of 31.7% on circulatory problems in 2005, representing 10% of total deaths in the Brazil. It is probably related to the busy, stressed and sedentary lifestyle with disorderly exacerbated tobacco and alcoholic beverages. The issues are others, but the physicians are still needed.

Becoming a doctor consumes a minimum of 8 years. The medicine average salary is far from pay the effort made by the doctors while educational formation. There is an incentive for the doctor to look for profitable specialities in medicine. It is the shortage of the primary-care doctors and general practitioners, who work harder and earn less than other specialties. Weiyuan (2008) calls the disproportionate focus on hospitals and specialists of **hospital-centrism** and affirms it carries a considerable cost in terms of unnecessary medication and iatrogenesis. Government does not invest in the health care professional qualification and who are qualified often leaves the state, and even the country, to seek better wages and labour conditions.

Government and salaried employment demands the physicians to see more patients in less time. There is a pressure to higher productivity without any concern about the quality measure. Cabana *et al.* (2007) done a research in a level I public hospital of Pernambuco between August and December of 2004 to compare the prevalence of common mental disorders in physicians. From 186 physicians who work in the hospital, 124 of them participated of the research (table 2.1). The research analysed factors as the overload, sleep deprivation and distress with the job. The emergency physicians works for the state ($p < 0.0001$), they have multiple jobs ($p = 0.004$), greater weekly wokload ($\geq$ 71hours)($p = 0.007$), they presented a greater sensation of being overloaded ($95.74\%, p =$ 0.015) and they received up to 5 times the minimum salary at the hospital ($p < 0.0001$). 86% of them use to attend followed shifts and 82% have another job in the private hospital. The authors concluded that the emergency physicians, considering all aspects, present a hospital routine with the worst working conditions, especially if compared with the wards.

Table 2.1: Variables Related to the Physicians Routine (Cabana *et al.*, 2007).

Variables		Ward n=57	$n\%$	UTI $n = 17$	$n\%$	Emergency $n = 50$	$n\%$	p-value
Years since graduation	$6-11$	4	7.02	7	41.18	19	38	$p < 0.0001$
	$11-20$	20	35.09	8	47.06	21	42	
	$\geq$21	33	57.89	2	11.76	10	20	
Would keep career's choice?	Yes	47	82.46	13	76.47	31	62	$p = 0.055$
	No	10	17.54	4	23.53	19	38	
Number of places in which he works	Up to 2	17	30.36	2	11.76	3	6	$p = 0.004$
	$3-4$	31	55.36	8	47.06	35	70	
	≥ 5	8	14.29	7	41.18	12	24	
Two shifts in a row	Yes	15	34.09	14	82.35	73	86	$p < 0.0001$
	No	29	65.91	3	17.65	7	14	
Weekly hours dedicated to the office	1 - 6	10	22.73	8	80	12	41.38	$p = 0.002$
	≥ 7	34	77.27	2	20	17	58.62	
Employed in the private hospital system	Yes	49	85.96	15	88.24	41	82	p=0.785
	No	8	14.04	2	11.76	9	18	
Time in the hospital (years)	$1-10$	17	29.82	10	58.82	33	67.35	$p < 0.0001$
	≥ 11	40	70.18	7	41.18	16	32.65	
Time in the sector (years)	Up to 5	15	26.79	2	11.76	17	34	$p = 0.120$
	$6-10$	14	25	7	41.18	19	38	
	≥ 11	27	48.21	8	47.06	14	28	
Salary in the hospital A (minimum wage)	Yes	49	85.96	15	88.24	41	82	$p = 0.785$
	No	8	14.04	2	11.76	9	18	

The private institution has better technological infrastructure. And if the physician is remunerated by the number of examinations, he will always be better paid in private institutions and the public hospitals will get tired physicians in rush to go to the other jobs. At first, the patient used to pay directly to the physician and now this payment is done by third parties. To compensate the same standard of living, to maximize their profit, they work in various different offices and hospitals (Montenegro, 2006). It limits their access to better qualifications and it increases the probability of a misdiagnosed patient. They try to compensate the reduced salary with the workload. It is the same problem when they are remunerated by their productivity.

Another research done by the Federal Board of Medicine (Conselho Federal de Medicina, CFM) between 2010 and 2012 reveled the wrong distribution of physicians in Pernambuco. The capital of Pernambuco has 6.27 doctors registered with the medical council for every thousand inhabitants. It is above the Rio de Janeiro (sixth place) and even São Paulo (eleventh). There are approximately 14,000 physicians of Pernambuco and more than 9,000 are in the capital. The national average of medical demography is two physicians per thousand people. Pernambuco is the 11th in the national ranking and the 1st in the Northeast, with 1.57 physicians per 1,000 inhabitants.

The World Health Organization (WHO) recommends one physician per thousand inhabitants which means the problem of physicians in Brazil is not the lack of professional, but the wrong distribution of them and the interiorization process of the health professionals. The solution is not creating private universities of medicine nor even extending the medicine public universities for the inner part of the state. Both solutions tend to reduce the quality of the medicine course and may not solve the problem at all. The government should create incentives for the physicians better distribution along the country.

The Health Insurance

To minimize the uncertainty and risk, people hire health insurances. But insurances have a personal perspective: to consider an insurable event will depend on economic resources and personal risk tolerance, at minimum. When a health insurance company insures an individual, the client knows more than the company about his inherent health problems and hence about his probability of having a disease, not considering the unexpected events. There is asymmetric information in the insurance markets. The insurance cannot cover 100% of the health situations because people would not take care of their health and the society would be more careless. That is why there is a price differentiation in the insurance market. The risk aversion person will pay far more than other people, not considering the budget constraint. It allows people with less economic conditions to have access to the low-price insurance operators. To avoid this adverse selection mechanism, some insurance companies impose clauses about preexistent diseases and demands a minimum time before having specific treatments.

Health insurances reduce considerably the price paid by the consumer and may significantly influence the demand for health. For example, the 'hospital care only' insurance induces unnecessary hospitalization because any ambulatory treatment will be paid out by the consumer. From the physician, there is a solicitation of an excessive number of complementary exams to reduce the margin of error, since the patient is not paying for each one of them. On the other hand, if the health insurance does not cover high complexity services, the patient will call on SUS services. Some physicians are not accepting health insurances anymore because of this conflict of interests. The higher the number of users with private health insurance, the lower is the overload of the Public Health System (SUS). The private health insurance is a complementary service to the SUS, guaranteing the health attendance to the whole population of a region. Because of this relationship among health insurances and the SUS, the Article 32 of Law n. No 9656, dated 03 June 1998, states that the service provided by public hospitals to health insurance users or dependent should be repaid to the SUS. The consumers of health insurance must choose wisely the health insurance and be consciousness about unnecessary treatment because in the end, the cost will return for the insurance consumers.

The Users of the Health Services

The time that patients spend getting health care services should be reflected in the way it is calculated the national health care expenditures, said Alan Krueger[2] in the New York Times. The idle time the user in the ambulatories and check-ups queues could be used for other rentable activities in the economy. The physicians delays compromises the users expectations about the treatment to be received. Technology and queuing management can reduce the waiting impact for the patients.

Users perceptions can measure the quality of the health care. Perception of a consumer has the influence of his/her expectations. A SUS user has lower expectations than a

[2]Professor of Economics and Public Affairs at Princeton University and Research Associate at the National Bureau of Economic Research

patient in the private system – the last one spends more money to have a better service and will demand more quality, in general. Nowadays the patient does not just accept the physician decision. With the advent of the internet, most part of the population have access to huge quantity of information and it changed the patient-doctor relationship, it changed the patient perceptions: they are not only passive receivers of care. Of course the free access to the information does not mean high quality information. It demands from physicians to deal with this new scenario.

The Applied Economic Research Institute (IPEA) did a domiciliar research in 2010 to measure the perception of the Brazilian families about the health services – The Social Perception Indicators System (SIPS). The questionnaires were applied in a sample of 2,773 people living in permanent private households. The parameters for choosing the sample distribution were based in the National Research per Households Sample (PNAD) conducted in 2008 by the Brazilian Institute of Geography and Statistics (IBGE).

Among other public health services, as health centers, specialized physicians, urgencies and emergencies and medicines distributions, the Family Health Program (Programa de Saúde na Família, PSF) was the best evaluated service. 80,7% of the interviewed people who received a member of the PSF team at home rated the service as "good" or "very good". Only 5,7% rated this program as "bad" or "very bad".

Among other public health services as vaccination, the fight against Dengue, Popular Pharmacy, SAMU 192 and UPA 24h; the Family Health Program (7.0 in a scale from 0 to 10) was not so well rated only better than the UPA 24h (6.6). The best rated program was the Vaccination with 8.8 points. This research was done by IBOPE (Brazilian Institute of Public Opinion and Statistics) at the request of National Industry Confederation (Confederação Nacional das Indústrias, CNI). 2.002 people were interviewed with an age above 16 years old, in September of 2011. According to this research, 61% of the people consider the health service of the country as "poorly" or "bad" and 85% did not perceive improvements in the Brazilian public health services in the last three years.

According to the interviews, the major problems of SUS are:

1. Lack of physicians — 58%

2. The waiting to Health Centers Services — 35.4%

3. The waiting to schedule and appointment with specialized physicians — 33.8%

Increasing the number os physicians is the main suggestion (46,9%). To reduce the waiting time between appointment and the consult is a suggestion to specialized physicians (34%) and the health centers (15.5%). 32% of the sample are also unsatisfied about the waiting time to emergency services. For the distribution of medicines, the main suggestion is to increase the list of free distributed medicines (43%).

And the main benefits of SUS service are:

1. Free access to the health services — 52.7%
2. No distinction in the attendance (Universality) — 48%
3. Free distribution of medicines — 32.8%

This result is totally aligned with SUS principles: universality, equity and integration.

On the other hand, people choose to hire health insurances, even the low-quality-low-price health, compromising a considerable fraction of the family budget in order to reduce of the SUS services. 40% of SIPS interviewed affirm to have the insurance for speeding in appointments and medical examinations. A similar research was made by Mauricio de Nassau Institute in July of 2012 with 624 people in Recife and the main suggestion was to increase the speed in the scheduling of the appointments. It means that despite people hire health insurance because of its higher speed in health services comparable to the SUS services, people are not totally satisfied.

2.2.2 The Demand

In the classical approach to consumer demand, the analysis of consumer behaviour begins by specifying the consumer's preference over the commodity bundles in the consumption set (Mas-Colell *et al.*, 1995). But the health demand by the population standpoint is unpredictable, it is a random variable distribution. Past experiences with others cannot be knowledge to reduce the uncertainty and disease risk.

According to Arrow (1963) there would be a model in which the individual who fails to be immunized could pay to anyone whose health is endangered, a price sufficiently high so that the others would feel compensated; or, alternatively, there would be a price which would be paid to him by others to induce him to be immunized. The immunization procedure can be thought as any preventive care – vaccine, annual check ups, nutrition, physical exercises. Higher prices in the health care services reduce the available income, because of the inelastic characteristic of the product. If there is an increase in the hospital admission prices, it can reduce the outpatient care access to the health services but not the existing demand. The demand for health services does not take into consideration the distributive questions and, thereat, it is inequitable.

According to the PNAD 2008, 55.6% of the people assisted in the health system and 67.65% of the hospitalizations were financed by SUS. The SUS did not finance only low cost services, but mainly the high cost services – 73.3% of the chemotherapy, radiotherapy hemodialysis and hemo-therapy services were financed by SUS. The poorest Brazilian regions are using more the health service: 81.9% of the population in the North of Brazil and 83.9% of the population in the Northeast of Brazil use the SUS services, while the other regions do not use more than 67% each – which means that the equality characteristics of the SUS is being reached. The table 2.2 adapted from Porto *et al.* (2011) shows the percentage use of the SUS services divided for income decile[3]. It is important to notice that the SUS covered almost 88% of health service for the poorest people and over than 50% percent of the seventh income decile, which means there are people not covered by the SUS yet. The richest people still use the SUS services (17%) probably because of the insurance companions regulations (higher cost services).

In terms of type of the health service demand, the World Health Organization (WHO) ranked the 10 most killing diseases in 2010 (figure 2.3). According to the WHO, cardiovascular and cerebrovascular diseases have very similar risk factors: hypertension, diabetes, high cholesterol, inadequate nutrition, sedentary lifestyle, smoking and harmful alcohol use. The scenario is that people are dying because of the bad quality of life associated with high level of stress. More people died because of diabetes than because of pneumonia in 2000, while in 2010 occurred the opposite. More people are dying because of

[3]Considering the whole population ranked by the income and divided in ten equal parts (deciles), each decile corresponds a part of this distribution. The first part is the poorest one and the 10th part is the richest one.

Table 2.2: SUS Services and Hospitalizations - PNAD - Brazil, 2008.

Income Decile	SUS Services (%)	N Total	SUS Hospitalizations (%)	N Total
1	87.6	3,123,573	92.5	2,151,960
2	86.4	1,553,149	91.5	902,829
3	83.0	2,247,721	88.2	1,282,719
4	75.9	2,501,825	84.7	1,434,248
5	70.4	2,417,044	77.3	1,259,995
6	63.7	2,688,415	74.3	1,281,806
7	56.3	2,392,265	64.9	1,167,633
8	41.5	2,642,542	50.8	1,180,607
9	25.0	2,819,122	32.1	1,211,505
10	16.8	3,066,104	23.4	1,242,787

hypertensive problem.

Table 2.3: The most killing diseases in Brazil - 2000 vs 2010.

#	Most Killing Diseases	2000	2010
1	Cerebrovascular Disease	84.713	99.159
2	Myocardial infarction	59.297	79.297
3	Pneumonia	29.348	54.986
4	Diabetes mellitus	35.284	54.542
5	Hypertensive Diseases	23.721	44.460
6	Bronchitis, emphysema, asthma	33.173	40.360
7	Heart Failure	28.195	27.402
8	Lung Cancer	14.655	21.715
9	Another ischemic heart disease	19.159	20.111
10	Cirrhosis and chronic liver diseases	15.495	19.235

2.3 Accountability, Quality and Transparency in the Hospitals

People are living longer and with this aging population comes an increase in the incidence of chronic diseases. But the health system is poorly organized to handle the new challenges. In 2001, the Institute of Medicine outlined six Aims for Improvement for health care[4]:

1. Safety: avoiding injuries to patients from the care that is intended to help them;

[4]The report “Crossing the Quality Chasm: a New Health System for the 21st Century” can be found in http://www.iom.edu

2. Effectiveness: providing services based on scientific knowledge and refraining from providing services to those not likely to benefit from them;

3. Patient-centered services: providing care that is respectful of and responsive to individual patient preferences, needs, and values, and ensuring that patient values guide all clinical decisions;

4. Timely: reducing waits and sometimes harmful delays for both those who receive and those who give care;

5. Efficiency: avoiding waste, including waste of equipment, supplies, ideas and energy.

6. Equitable care: providing care that does not vary in quality because of personal characteristics such as gender, geographic location or socioeconomic status.

Quality requires continuous assessment, management and improvement of processes. According to La Forgia ˙ Couttolenc (2008), any efforts to improve the quality and efficiency of public hospitals in Brazil will rely on increasing the motivation and proactivity of hospital managers and employees. It is not only to establish a performance-based contract for the health professionals, but to allow flexible work hours, to guarantee contract enforcements and a robust information environment. These actions associated to an increase of the autonomy of the hospitals can increase the accountability of most hospitals. The idea of accountability is really attractable at first, but it requires considerable changes in the hospital routine, specially for the physicians and nurses. Porter ˙ Teisberg (2007) affirms that many physicians fear that more outcome measures would increase the risk of practice claims. And the opposite is what happens, because physicians will be better able to prevent themselves from bad outcomes. It will be easier to document complications and analyse them. To follow procedures and maintain records of their own performance demands extra-time and patience and, in general, they do not see the direct result of the data recording. It is not enough the data to be collected periodically, must exists a comparative analysis, reporting and implementation of the suggested changes to guarantee the improvement. The hospitals should hire *think tank* professionals to measure, analyse, suggests and implement structural changes to improve the hospital performance indicators.

In his book, *Unaccountable: What hospitals won't tell you and how transparency can revolutionize health care*, Dr. Makary exposes uncomfortable truths about the hospitals quality in United States. Only the health care workers are able to understand everything that happens inside of the system. From impaired physicians until unnecessary treatments, the author explains about non-spoken issues in the hospital-patient care. An example is the 'never event':

> *Never events should absolutely never happen in a hospital. Different from complications, which cannot be completely eliminated, never events are by definition avoidable. They include leaving sponges or instruments inside a patient after surgery, performing the wrong operation or the right one on the wrong side or the wrong patient. These catastrophes should simply never occur. Never events sound shocking, but most every hospital in the country, including every hospital I have ever worked in, has had at least a couple every year. (Makary, 2012)*

Without publicly available metrics of a hospital's outcomes, how can people choose where to go? As in many other countries, the absence of reliable data, systematic measurement and institutional infrastructure for monitoring and evaluating quality frustrates most attempts to assess the quality of care in Brazilian hospitals (La Forgia ˙ Couttolenc, 2008). People should have online access to the hospital performance database. The numbers of 'never events', infection rates, patient outcomes and patient satisfaction in the hospitals should be available.

Hospital quality is also affected by the quality of professional practise. The healthcare system acts as the lemon market of the economy: the hospitals knows more about the product (the health care) than the buyers (the patients). Because of the asymmetric information, the patient cannot differentiates excellent physicians from bad physicians. It covers up the bad-performance physicians, does not promote the excellent physicians and can even reduce the average efficiency of the health in the system. If it is not possible to measure it, it is difficult to improve it. Accountability in the health system would expose dangerous doctors and reward good performance. Transparency can improve the patient experience and revolutionize the health care system.

2.4 The Motorcycle Costs for the Health Sector

Cabral *et al.* (2011) analysed the epidemiology of the accidents in the land transport accidents in the municipality of Olinda from July of 2006 until June of 2007 and they found that pedestrians, cyclists and motorcycle occupants concentrate 78% of the victims. The motorcycle was the major cause of the running overs (43%). This type of study is important to define policies to prevent the cause of the accidents.

Since 1989 is mandatory the use of the safe belt, but only in 1998 the law came into effect in the national roads. The mandatory use of the safe belt represented an advance in the protection of the car user population, considerably reducing the mortality in car accidents. According to the National Traffic Department (DENATRAN) and the Information System Mortality of the Health Minister (SIM/MS) databases, from 1998 to 2008, the mortality in motorcycle accidents had increased in 29.2% considering the raise in motorcycle sales: it was a raise of 79% in the motorcycle sales and an impressive increase of 83% in the victims of this type of accident in ten years. While there was a decrease in the car accident considering the variation in the car sales – because it was an increase of 47% in the car sales and 36% in the car accident victims.

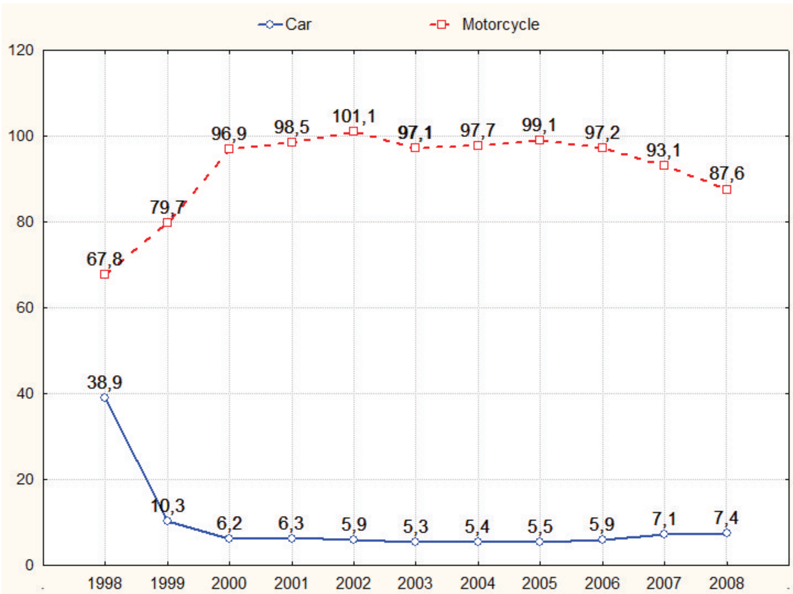

Figure 2.3: Victims Rate Evolution per Vehicle in Traffic Accidents. DENATRAN, Brazil. 1998-2008.

According to the State Committee for Prevention of Motorcycle Accidents, in 2011, around 160 of 3,250 victims of motorcycle accident who underwent surgery in *Hospital da*

Restauração, Hospital Getúlio Vargas and Hospital Otávio de Freitas ended paraplegics. After the installation of UPA's, just the most severe cases go to the Hospital. Most of the motorcyclist injured in 2011 had only elementary school (21.12%) or high school (25.04%) completed. It must say a lot about the economy: not speaking about the low investment in education, there is a pressure to find a job and keeping it.

The motorcyclist provides important service to the firms, rapidly bringing and leaving documents and orders. But it is a high risk activity, mostly because they imprudently move between cars and sometimes faster than the limit speed. Motorcyclists are more susceptible to have accidents. The human lost and social cost are high, because in general, these professionals are registered as autonomous and do not have a health insurance. In a case of an accident, they end up going to a public hospital, sometimes for months, and most often they go out of the hospital with permanent *sequelae* and unemployed. Less productivity to the economy. To reduce motorcycle accident, traffic education is demanded. The Operation Alcohol Prohibition (*Lei Seca*)[5] has been reducing traffic accident but has not actually an educational goal, people are respecting the law because of its punishment, not because of their consciousness. Before consider the reduce in the Industrialized Products Tax (IPI) to incentive motorcycles sales, the government should consider how this can affect the health investments.

[5]Since November of 2011 it is a crime to drive under the influence of any alcohol level.

3 THE WAITING LINES

The waiting lines are an important and central topic in operations research.

3.1 What are they?

A QUEUEING SYSTEM can be described as patients arriving for service, waiting for the service if they are not immediate served, utilizing the service, and leaving the system after being served (Kleinrock, 1975). In queueing studies it is necessary to estimate the probability distribution or pattern of the arrival times between successive patient arrivals, the inter-arrival times (Johnson, 2008). The probability distribution of the service times depends on the numbers of patients in line and the experience of the server. Usually we assume that the service times are independent and identically distributed, and that they are independent of the inter-arrival times (Adan ˙ Resing, 2001). The patient arrival pattern is assumed to be independent. It is also important to know the **number of servers**, the **capacity of the system** and the **queue discipline**.

The number of channels defines the number of parallel services that can serve the arrival customers simultaneously. A multichannel system with a unique queue differs from a multichannel system with one queue for each server. In some queue processes there is a physical limitation of the capacity of service and as long as the queue reaches a given length, which will depend on the system, no other new customer can enters in the system until there is available space. It happens because one is dealing with finite queueing systems. A system in which every customer who enters is served is a system with infinite capacity.

Queue discipline describes how the customers are served after a queue has been formed. The only parameter that depends on the discipline of the queues is the variance of the waiting time. The queue discipline specifies the disposition of the customers who find all services busy — blocked customers. It can be an orderly queue First in First out (FIFO), also known as First Come First Served (FCFS). Or in the reverse order: Last in Last out (LILO), as in an elevator, for instance. It can be a priority queue or a Service in

Random Order (SRO). Although FIFO is the most common queue discipline, in the case of hospital queues it is required to establish a priority queue discipline, because FIFO does not respect the emergencies. The queue discipline is considered to calculate the individual waiting times.

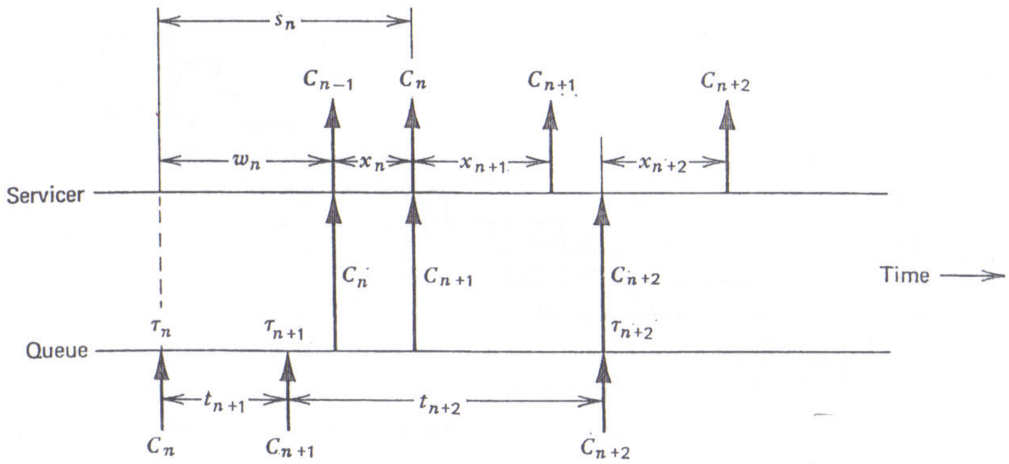

Figure 3.1: Time-diagram notation for queues (Kleinrock, 1975).

This figure represents a first-come-first-serve order of service. The arrow approaching the queue line from below indicates that an arrival has occurred to the queue. The customer C_{n+1} arrives before customer C_n enters on service. and C_{n+1} is only attended when C_n departs from service. C_{n+2} enters immediately in the system, since it is idle. As time go on it is possible to identify the number of customers in the system, $L(t)$.

There are two general situations of priority disciplines – preemptive and non-preemptive. In the preemptive case, the patient with highest priority is allowed to enter in service independently of which service is happening in a patient with lowest priority. The service of the lowest priority person is suspended to give the priority and it will continue or restart later. In the non-preemptive case the customer with highest priority go to the beginning of the queue but only enters in service after the customer in service goes out of the system.

The waiting line represents the balance between demand and supply. If there is excess in the supply, there will be stock in the firms. And if there is excess in the demand, there will be queues. The health sector, erroneously, has been calculating the payment of the investment in technology based only in the production capacity, not considering the demand as a restriction. It leads to a high supply of services.

There are two decision makers in a queue – the manager of the system and the customer. Since different people have different preferences, the manager cannot see the utility of every single customer to decide which amount of time will be the maximum in the waiting line. The managers have to decide the right number of servers to not have unnecessary costs – when there is idle capacity – nor lose 'customers' because of the high level of waiting time – when there are no servers enough to attend the arrival rate.

The queue can be considered as the time spent in the line or as the total time a customer spends in the system: queue plus service. The most interesting to study will depend on the objective of the service manager. The client wants a good service in the minimum time. He can decide between enter in the line or not. The higher is the 'service value' for the customer more time he will be willing to wait. If he decides to wait and then gives up, it is called "reneging". If he looks at the queue and decides to not get in, it is called "balking". And the most common: if he keeps changing the queue, it is called "jockeying". The service manager wants to maximize profits. And for this, he will need to concern about his client, improving technology and increasing the number (or efficiency) of servers in the system if it is necessary. It is important that the arrival rate (λ) to be less than the service rate (μ): $\lambda < \mu$. In the 'Hospital da Restauração' restaurant preliminary study, this relationship was 4 customers per minute to 0.5 served per minute, which is a critical situation.

3.2 The Psychology of Waiting Lines

> *If you expect a certain level of service, and perceive the service reviewed to be higher, you are a satisfied client. If you perceive the same level as before, but expected higher, you are disappointed and, consequently, a dissatisfied client. (Maister, 1985)*

In 1985, Maister determined a formula to describe satisfaction:

$$\text{Satisfaction} = \text{Perception} - \text{Expectation} \tag{3.2.1}$$

Some people have a higher disutility in a queue than other people. It can be said that there is a diminishing marginal disutility of waiting line. In other words, there will be people refusing to wait for long time because at certain point the utility of the service is minor and it will decrease. It will depends on the value of the service for each person. That is why there are people willing to pay for not wait in queues. Today, with the advent of the internet and the improvement of technology it is easier to avoid 'physical queues'.

Everybody has once confronted a situation in which you have to face a queue to have a service done but the time is short because there is a deadline to meet – maybe a business meeting or to pick up your son in the school. People who not have enough information about the waiting time will stay anxious. Emotions dominate the whole sensation about the experience in waiting lines. The objective of the system managers is to make this experience as better as possible. For that, queues have to be fair, clear, efficient and as always as possible pleasant.

Anxiety makes waits seem longer (Maister, 1985). The famous sensation that the other queue always moves faster can be solved with a single queue. Single lines move more quickly than multiple lines even for a higher total numbers of customers – because it redistributes the variance of the server in answer the demand – and the perception of fairness is better. With multiple lines people can see when the other lines are moving faster, but they do not perceive when their line is the fastest one. This creates a feeling of unfairness which can worsen the waiting experience. If there are three lines (A, B and C) and it is random that any of this line will have a delay, there are six possible arrangements from the fastest to the slowest in any particular moment. It could be the A moving faster (ABC or ACB), the B moving faster (BAC or BCA) or the C (CAB or CBA). In only two of these six permutations will come out if you are at queue A, for example. It is one chance in three for your line to be moving faster which is more than 66% that the other lines are passing yours. Any queueing layout needs to transmit a fairness feeling, that is why a single queue is better for most cases.

Uncertain and unexplained delays cause anxiety and make the wait seems longer than it really is. In physician's office, people can arrive considerably earlier than the appointment to guarantee their attendance but they get extremely annoyed if the doctor do not start on the right time. Maister calls it "the appointment syndrome". To advice people about the estimated waiting time can reduce their tension because they can do other activities while the system is not ready for them. It is necessary to provide a clear, unambiguous conceptual model of how the line operates, where people should enter, what is expected and how long it will take (Norman, 2008).

People have less eagerness if they perceived they are in service already. According to Maister (1985) there is a fear of "being forgotten" so the patients have to feel they entered in the system even if they are not in treatment yet. The patients need to be aware about the waiting time. While waiting, people can watch videos about health and welfare or they can read folder about health care – they have to be entertained. In triage systems – with nurses checking the symptoms of the patients and deciding whether the patient should see a physician – patients do not have the consciousness of the queue and perceive it as a part of the service. Must exist a determined pattern for the most common procedures, so they will take less time to be completed.

3.3 Mathematical Models

The queueing systems goes beyond the simple introduction made in this chapter. From the elementary mathematics until the advanced material it is required to understand stochastic models to study queueing theory. This section is adapted from Kleinrock (1975).

3.3.1 Taxonomy of the Queue Models

Kendall's classification of queueing systems (1953) exists in several modifications. The most common is defined with four letters: $A/B/m/k$. The first letter specifies the inter-arrival time distribution and the second one the service time distribution. Following is the number of servers and then the maximum number of customers allowed at any one time. G is used for general distribution, H_R for R-stage hyperexponential distributions, E_r for r-stage Erlang distributions, M (memoryless) for the exponential distribution and D for deterministic times. It means, a queue defined as $M/M/1$ or $M/M/1/\infty$ is a single server queue with Poisson arrivals, exponentially distributed service times and infinite number of waiting positions.

3.3.2 A Basic Model

The **arrival process** describes how the clients arrive on the queue. The time between the arrivals are not known thus the arrival process is described in terms of the probability distribution of the inter-arrival times of customers. The interarrival times are random variables so the arrival process has stochastic behaviour. The arrival process can be represented as:

$$A(t) = P[\text{time between arrivals} \leq t] \tag{3.3.1}$$

It is assumed that these inter-arrival times are independent and identically distributed random variables. In a basic model the inter-arrival probability distribution is the exponential probability, memoryless characteristic. For an inter-arrival time exponentially distributed, the number of arrivals in this time interval follows a Poisson distribution. It is important to notice that the exponential distribution is not symmetric. The average inter-arrival time between customers is $\frac{1}{\lambda}$, where λ is the average arrival rate of customers.

The **service time** is the amount of demand the arrivals remained upon service. The parameter for this exponential distribution is μ, which is the average service rate. The service time can be considered as

$$E(x) = P[\text{service time} \leq x] \tag{3.3.2}$$

Considering C_n as the customer n. x is the service time for C_n. And t_n can be considered as *the arrival time for* C_n *- the arrival time for* C_{n-1}, one has:

$$A(t) = P[t_n \leq t] \tag{3.3.3}$$

And the same way for the service time:

$$B(x) = P[b_n \leq x] \tag{3.3.4}$$

Considering the time spent in the queue as w_n and the total time spent in the system for C_n as s_n, then:

$$s_n = w_n + x_n \tag{3.3.5}$$

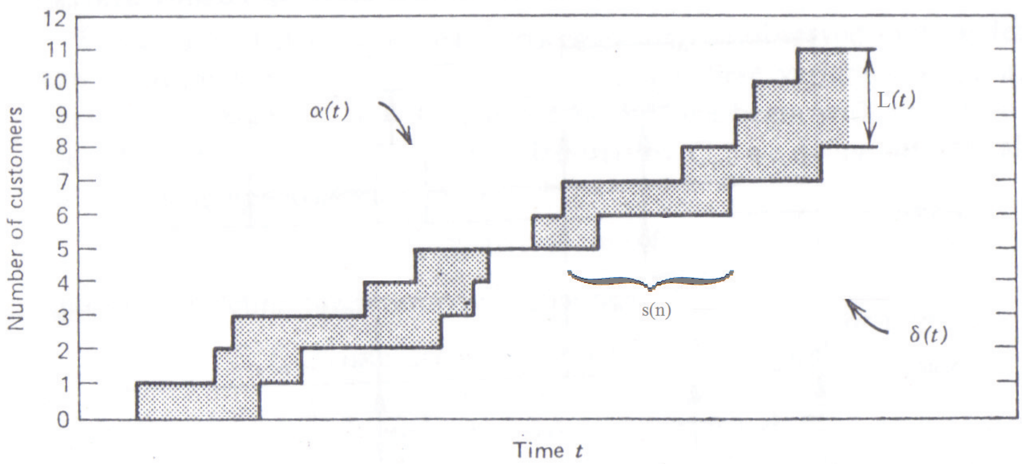

Figure 3.2: Arrival and Departures (Kleinrock, 1975).

The height in the upper side of the figure (3.2) represents the number of customer who arrived in the system in $(0, t)$ while the height in the lower side of the figure represents the number of customers who already departed.

$L(t) = \alpha(t) - \delta(t)$

Denominating the number of arrivals in $(0, t)$ as $\alpha(t)$ and the number of departures in $(0, t)$ as $\delta(t)$, then the arrival time λ can be represented as $\lambda_t = \frac{\alpha(t)}{t}$.

Little's Law

Little's law gives a very important relation between the average number of customers in the system $\overline{L}$, the mean 'sojourn' time W and the average number of customers entering the system per unit time λ. It affirms that

$$\overline{L} = \lambda W \tag{3.3.6}$$

It means that the average number of customers in a queueing system is equal to the average arrival rate of customers to that system times the average time the client spent in the system. The Little's law does not depend upon any assumption regarding the arrival distribution nor the service time distribution.

The Litte's law to calculate only the server(s) is $\overline{L} = \lambda\overline{x}$, in where $\overline{x}$ is the average time spent in the service box.

3.3.3 Markov Processes

A stochastic process is a family of random variables indexed by the time parameter t represented by $X = X(t), t \in T$ where T is the set of indexes or parameters which can be of any nature, since it belongs to the set of real numbers. About the state space, it can be discrete-state process – or chain – if the positions that particle may occupy are finite or countable. Or it can be continuous-state process if the the positions of the particles are over a finite or infinite continuous interval. A stochastic process $X(t)$ is stationary if the finite-dimensional distribution function is invariant to shifts in time for all values of its arguments.

A Markov process has exponential distribution (memoryless). A markov chain is a markov process with a discrete state space. A set of random variables X_n forms a Markov chain if the probability of the next state x_{n+1} depends only upon the current state x_n and not upon any previous values.

The Birth-Death process is a special class of Markov chains. The defining condition is that state transitions take place between neighboring states only. The birth-death process requires that if $X_n = i$ then $X_{n+1} = i - 1$, i or $i + 1$ and no other. The events are statistically independent and may be either discrete or continuous time processes.

A Markov chain with continuous parameter in where the state transitions is only allowed for the next state is a Poisson process, or Pure Birth. The Poisson Process requires that if $X_n = i$ then $X_{n+1} = i + 1$ in a constant rate. It is the same of a birth-death process with the death rate zero ($\lambda_n = \lambda; \mu_n = 0$).

The $M/M/1$ Model

The probability distribution of the inter-arrival time and the service time are exponential. The capacity of the system is infinity and the queue discipline is FCFS. For $\lambda < \mu$

in a stead state the following calculus can be done:

Usage of the system:

$$\rho = \frac{\lambda}{\mu}$$

Expected number of customers in the system:

$$L = \frac{\lambda}{\mu - \lambda}$$

Expected number of customers in the queue (Length):

$$L_q = \frac{\lambda^2}{\mu\,(\mu - \lambda)}$$

Expected waiting time in the system for :

$$W = \frac{1}{\mu - \lambda}$$

Expected waiting time in the queue:

$$W_q = \frac{\lambda}{\mu(\mu - \lambda)}$$

Probability of the system being idle:

$$P_0 = 1 - \frac{\lambda}{\mu}$$

Probability to have n customers in the system:

$$P_n = \rho^n(1 - \rho)$$

Probability of the waiting time be higher than $t > 0$:

$$P(T_q > t) = \rho e^{-(\mu-\lambda)^t}$$

In where T is the average system (sojourn) time; T_t is the system time per customer averaged over all customers in the interval (0,t) and $\overline{L}_t$ is the average number of customers in the queueing system during the interval (0,t).

The $M/G/1$ Model

There are cases in which the exponential distribution does not describe exactly the arrival process. For these, there is a generalization of the basic model. It is not necessary to know the service time, only its mean $\frac{1}{\lambda}$ and variance σ^2. As long as σ^2 increases, L, L_q, W and W_q also increase.

Usage of the system:

$$\rho = \frac{\lambda}{\mu}$$

Expected number of customers in the system:

$$L = L_q + \frac{\lambda}{\mu}$$

Expected number of customers in the queue (Length):

$$L_q = \frac{\lambda^2\sigma^2 + \frac{\lambda}{\mu}^2}{2\left(1 - \frac{\lambda}{\mu}\right)}$$

Expected waiting time in the system for :

$$W = W_q + \frac{1}{\mu}$$

Expected waiting time in the queue:

$$W_q = \frac{L_q}{\lambda}$$

Probability of the system being idle:

$$P_0 = 1 - \frac{\lambda}{\mu}$$

Queueing Network

Jackson's theorem states that in a network queues each node is an independent queueing system. It is assumed infinite capacity for all queues. For real systems this infinite capacity assumption does not hold, but is often maintained due to the difficulty of grasping the between-queue correlation structure present in finite capacity networks (Osorio ˙ Bierlaire, 2007). At time t, the state of the network is defined by a vector $(k_1, k_2, ..., k_M)$ which is further assumed to be a Markov process, with probability $P_{k_1,...k_M}(t)$. The theorem is based on three assumptions:

1. The queueing network consists of m nodes, each of which provides an independent exponential service.
2. Items arriving from outside the system to any one of the nodes, arrive with Poisson rate.
3. Once served at a node, an items goes immediately to one of the other nodes with fixed probability.

If these conditions is satisfied, each node is an independent queueing system.

4 THE WAITING LINES IN THE HEALTH SECTOR

The waiting lines in the Brazilian health system is a recurrent and very serious problem.

4.1 The Health Waiting Lines — Literature Review

The time spent in the waiting lines depreciates the present value of the service and it will raise the price of the treatment for the patient in the end of the line, because the condition of the patient deteriorates. Expanding the physical capacity reduces waiting lines, but it demands financial resources. At some point, only increasing the capacity will not solve the problem of deadlines because of the Diminishing Returns to Scale related to the management capacity. For the SUS, the queues cause a loss in the social reputation. The patient expects an attendance and if his condition is too damaged a waiting line will not reach his expectations, so population will not look for a public health care any more because no one wants to take risks when dealing with the health.

In general, in the health system the queue is not only the waiting list in which the attendance can be waited out of the line. A queue demands the physical presence of the patient, frequently in bad conditions — improvised beds (Marinho, 2009). It is worse for elder patients or patients in serious situation, who demands companions. In order to improve performance in an environment as complex as a hospital system, the dynamic at work need to be understood. To obtain such an understanding, queueing theory and simulation provide an ideal set of tools (Creemers ˙ Lambrecht, 2007).

The intensive care unit (ICU) of a hospital is an essentially costly resource (Griffiths *et al.*, 2005). This is why Jiang ˙ Giachetti (2007) analyses the patient cycle time to model the urgent care center trough multi-class open queueing network model (MOQN). Griffiths *et al.* (2005) utilized simulation in their analysis with the argument to be better to the hospital managers to comprehend a non-mathematical language. Jiang ˙ Giachetti (2007) utilized in each node of the queueing network a GI[1]/G/1 or GI/G/m queue instead of a M/M/1 or M/M/m, better representing service time distributions found in health care. The queueing network model is good when analysts just need a critical information

[1] General Independent distribution.

of the system instead of very detailed information that a simulation model can provide.

Barros ˙ Olivella (2005) analyse the non-urgent treatments for a certain specialty with some degree of prioritization, but mild. Examples of non-urgent treatments with long waiting lists and mild prioritization regimes are the surgery of cataracts, hernia and elective heart surgery. The authors developed a positive model of waiting lists for public hospitals when physicians deliver both private and public treatment. And show that physicians do not necessarily select the mildest cases (easiest treatment) from the waiting list — when the selection is made by them. Besley *et al.* (1999) also analyses the association between the private system and the public waiting lines. It is important to notice that each treatment in the private system reduces the waiting list in the public system, but since the private system has a financial cost despite its quickness, depending on the case, the patient will decide to have the queueing cost.

Gonçalves *et al.* (2007) utilized the Data Envelopment Analysis (DEA) for the performance evaluation of the medical public hospital admission. The authors used the Constant Returns to Scale Model to generate the scores to evaluate the efficiency of the unities. Freitas (2002) utilized the same methodology to study the efficiency of the Recife Medical Center. The hospitals face a paradox between a high occupancy rate and financial instability so it is demanded a management system. Freitas states that the mainly problem of the insurance companies is to calculate a saving account to support the system utilization. The public health system utilization versus private insurances and how it affects the waiting times can be found in Iversen ˙ Kopperud (2005).

To reduce waiting lists, the Swedish Government and the Federation of County Councils agreed on an initiative to offer a maximum waiting-time guarantee for 12 different procedures during 1992 (Hanning, 1996). The author compared the maximum waiting-time guaranteed with others effective approaches toward minimising queues in health care. Gerchak *et al.* (1996) provides a stochastic dynamic programming model for the allocation of resources in hospital's general surgery operating room. Iversen ˙ Lurs (2008) utilize a mathematical optimization to analyse which variables can influence the probability of patient switching in the Norwegian patient list system. Norway has a national health service financed by general taxation.

Planning and management of bed capacities must be evaluated within an environment of uncertainty, variability and limited resources (Harper ˙ Shahani, 2002). That is the reason for Gorunescu *et al.* (2002) had assumed a M/PH/c (PH is the Phase type distribution, a stochastic process) queue in steady state to optimize the number of beds in the geriatric hospital department in order to maintain an acceptable delay probability. M denotes Poisson (Markov) arrivals, the service distribution is phase-type, and c is the number of servers (beds). Koizumi (2002) identified a problem about the over-usage of the mental health facilities: many patients are spending unnecessarily extra days in psychiatric hospitals and community-type accommodations, leading to congestion. The author utilized for this analyses a open queueing network model with blocking. By explicitly modelling the blocking phase, the model yields a description of the congestion effects (Osorio ˙ Bierlaire, 2007).

There is an individual cost related with the waiting time. But in the case of Hospitals, this individual cost becomes a staffing level cost and a huge loss of financial resources for the Hospital: waiting time is non-working time. It is a loss of patience and mood for the workers, what can interfere in the treatment of the patients. Only for the hospital admission it was estimated a loss of 0,03% in the Gross Domestic Product (GDP) in Brazil at 2004 (Marinho, 2009). It is important to consider the criteria to prioritize the patients in a queue. Because of the time and resources restrictions, it is frequent for the physicians to have to decide the patient will have the surgery, considering the probability of success in the treatment or even the chance of survival of a patient. Brailsford *et al.* (2004) interviewed thirty key individuals across health and social care, establishing a 'conceptual map' of the system, which shows potential patient pathways through the system. This was used to construct a stock-flow model, populated with current activity data, in order to simulate patient flows and to identify system bottle-necks in Nottingham, England.

In Brazil, a significant percentage of the candidates for transplants die before an attendance: 54,5% for liver transplants in 2004, while the United States reported a mortality rate of 6%. Marinho (2006) analysed the waiting lines for solid organ transplants in Brazil's Unified National Health System utilizing a model M/M/1. The waiting lines

Brazilian studies in the health system has much yet to develop.

4.2 A Management Tool: The QualiSUS

THE most common complaints of the SUS users are related to the long queues without appropriate reception and with no risk classification, the low resolubility of the Primary Health-care and the service in the emergency units. The Qualification Policy for the Health Care (QUALISUS) was launched in 2003 to improve the quality of the service for the population. There are four mainly projects of the QualiSUS program:

1. Qualification of the service in the urgency and emergency units
2. Qualification of the Basic Attention
3. Qualification and Access to the ambulatory assistance and medium complexity hospitals
4. Humanization Policy of the SUS attention and management

The QualiSUS prioritizes the improvement of the urgency systems. And that is why the program is in consonance with the National Urgency Attention Policy (PNAU) which has the propose of organising and qualifying not only the urgency hospitals but the SAMU, the 'domicile' attention, the hospital beds and the emergency units. The QualiSUS also defends the humanization of the services to reach the quality in the health-care. This issue is represented in the National Humanization Policy (PNH, HumanizaSUS). This policy has been pursuing the reduction of queues and waiting times, the sheltering reception according to the risk classification, the enlargement of the territorial and social access, the participation in the hospital management, the guarantee of information access to the users and the companions of his/her social network[2]. Despite the hospitals do not present infrastructure to receive the companions the SUS aims to guarantee their presence in the hospital, because they create an environment with a minimum of comfort for the patient, which facilitates her/his recovery.

[2] More information about QualiSUS can be found in the Health Ministry website `http://portal.saude.gov.br`

The low resolubility of the primary health-care is one of the reasons for overcrowded hospitals. Other reasons are the geographic coverage of the hospital and the management failure. In general, the hospital does not have strategies to administrate the overcrowded. The staff get stressed and their remuneration depreciates because of the higher responsibility and effort demanded. The emergency units has been having troubles to deal with the non-severe incoming patients. There are plenty of causes for people use the emergency service inappropriately: easy accessibility, 24h service, queues for schedule appointments, absence of professionals in the health clinics, etc. Most attended patients could be served by ambulatories and a part of them will not proceed with the treatment of the symptom that motivated the search for emergency service, once the problem is apparently solved. Without a broad review of the health system, the emergency will continue to be inappropriately used by the patients as an option for the primary health-care (O'Dwyer *et al.*, 2009).

According to the Health Ministry, **to improve the quality of the service in the urgency hospitals** it is demanded to respect people rights to comfort, information, sheltering reception (Aspect I); to guarantee the diagnostic and therapeutic solutions with competent professionals and suitable infrastructure (Aspect II); to democratize and improve the management of the hospitals; and to integrate the urgency system. **To enhance the efficacy of the primary health-care** the professionals need to be trained for immediate solutions: the implementation of the Health Attention Family Centers, the guarantee of the prescribed medicines and the guarantee of the reference to the specialized service.

Besides the *Urgency and Emergency* and the *Primary Healthcare System*, the QualiSUS has two others main issues: the ***Cegonha* project** – special care to the mothers and their children – and the **Psycho-social attention** – the fight against drugs. All of them contributes to reduce the poorness in Brazil. To reach better results they will require investments in technology, innovation, productivity gains and improvement of the e¸ ciency, regulation and monitoring.

According to Gusmão-filho *et al.* (2010) Pernambuco is the second highest public hospital system of SUS. Three hospitals were inserted in the QualiSUS: *Hospital da Restauração*

(HR), *Hospital Otávio de Freitas* (HGOF) and *Hospital Getúlio Vargas* (HGV). All classified as Reference Hospital level III – medium and high complexity. The authors analysed the adequacy of the hospitals to the QualiSUS requirements according to the infrastructure and the working process. None of these hospitals researched implemented the "Normalization of the Medical Conducts".

4.3 A λ: The Walk-in Clinics (UPA's) and The Risk Classification

According to the Ordinance 2048 of the Health Ministry, the Reception and Risk Classification (ACCR) has to be done by a health professional with higher education, specifically trained about the protocols and patient treatment. There is no need to schedule an appointment (a walk-in clinic), the units work to reduce the congestion of the health system. The Reception with Risk Classification is a tool for the humanization policy. The UPA 24h has a high level of resolubility and it is a part of a Humanization of Health Care Program, prioritizing the time to reduce unnecessary pain, avoidable deaths, *sequelae* and hospital admissions. It constructs a system of attendance considering the whole health service network.

The UPAs are the attempt of the government to regulate the demand of the urgent services in the hospitals, it is a complement of the medium complexity emergency in SUS. Since it is not a device to diagnoses diseases, **does not replace the Basic Health Units for ambulatory treatments**. If a person has a seizure, he can go to an UPA to receive the medication. After the crisis the health professionals will send him home despite the patient may have a brain tumor or epilepsy. The UPA will not treat the disease, but the symptoms.

The UPA works 24 hours per day in the seven days of the week and can solve problems related to high blood pressure and high fever, fractures, incisions, heart attack and stroke. The UPAs innovate o´ering a simple structure with X Ray, electrocardiography, pediatric, laboratory and beds. After the attendance and controlling of the problem with a diagnosis, the professional team analyses if it is necessary to send the patient to a hospital or keep him in observation. In the classification criteria for the attendance the vital signs of patient are examined considering the individual characteristics (age, gender, pre-existing diseases), the pain scale, the Glasgow Coma Scale and communication di¸ cult (drugs, alcohol, mental disability). The classification end up with a bracelet with the color indicating the gravity of the patient.

Red priority – Emergency : Immediately directed to the resuscitation room and notify the ER sta¸. The buzzer is activated. People do not waste time with classification, the attendance is immediate in a maximum of 15 minutes. Imminent death cases as polytrauma, heart attack, cardiopulmonary arrest, severe burn, spinal cord injury, etc.

Yellow priority – Major urgency : Immediately directed to a consultation. Maximum waiting of 30 minutes, because the patient has a high risk of death. Traumatic Brain Injury (TBI) without loss of consciousness, minor burns, any severe pain whatsoever, mild to moderate dyspnea, abdominal pain, seizures, intense headaches, symptomatic elderly people and pregnant women, etc.

Green priority – Minor urgency : It is a minor urgency, as di¸use abdominal pain, cranial injury, minor headaches, migraine, psychiatric illness, diarrhea, asymptomatic pregnant and elderly people, etc. The patient can wait for at maximum one hour because there is no risk of death. After referral for speciality. He will be reassessed by the physician until the 'hospital discharge'.

Blue priority – Ambulatory : Until 120 minutes of waiting, depending on the demand. chronic complaints, bandages, flu, etc. These are cases that must be treated in the Basic Health Units (Health Centres).

It seems the population is not well informed about the usage of the UPAs yet. People go with chronic symptoms and do not want to wait for the attendance, maybe because they do not understand the prioritization system. The physicians spend attention and energy with the non-emergent cases and sometimes when a real emergency happens, the medical sta´ is physically and/or mentally tired. It happens mostly because there are not enough investments in the basic assistance treatment and it is absolutely common to not have physicians in the health centres. To cover this situation, the government of Recife is investing in twenty new health units to o´er outpatient care and emergency for less severe cases. These units (UPinhas) will operate 24 hours and each one will have three doctors, three dental o¸ ces, three teams of the Family Health Program and observation rooms, nebulization and suture. In addition, there will be space for sample collection and application of medications.

The S.O.S. emergency and the Better at Home (Melhor em Casa) Programs are other government adjustments to stimulate the λ in the health system. The S.O.S. emergency plans to improve the management and to qualify the service in the emergency rooms. Each hospital will receive *R*ı 3.6 million of the Health Ministry to the acquisition of material and equipment, to hire sta´, to investment in more beds or any spent related to the program. The Better at Home is a way of empty beds in the hospital to other urgency cases. The SUS patients who do not need hospital admission can be treated at home with public physicians and public equipments. The patient receives a bed and medical equipments to use at home. The Health Minister, Alexandre Padilha, a¸ rms that if these equipments need electric energy, the residence will have total exemption in the electricity tax needed to the equipments work. This program reduces the hospital queues and humanizes the treatment.

4.4 A μ: The Family Health Program (PSF)

In China there was a movement in 1978 inspiring the primary health care: the China's barefoot doctors. These health workers lived in the community they served, focused on prevention rather than cures while combining western and traditional medicines to educate people and provide basic treatment (Weiyuan, 2008). They were trained agents to orientate, take care and treat the common diseases in the population they attended, usually in countryside. Brazil adopted the PSF model (Family Health Program) in 1994, which started with the PACS (Health Community Agents Program) in 1991 in the Ceara. The PACS consolidated the importance of the home care and outpatient for the SUS and has a target to **reorganize the local health services** and to integrate the actions of various health professionals, so community and health units can have an e´ective *liaison*.

Both models are centred in the family, in the community, not in the hospital. Prioritizes the prevention and not the cure, avoiding people to get sick. For years the basic health care was not a priority for the Brazilian government and now this lack of investment creates huge expenses to treat diseases that have spread over because of the absence of investments in prevention, creating a vicious circle. The low e´ectiveness of the Basic Care Units, most of the time there is no physicians, makes the population go to hospitals – the hospital-centrism. The goal of the PSF implementation was to create a health care model closer to the family and consequently improve the Brazilians life quality. The program is financed by the variable part of the Primary Care Budget (PAB) with federal, state and local resources transference.

The PSF must be connected to the service network to guarantee a full attention to the family and community with equality, so it can be trusted as a bridge to the higher complexity health services – the reference and cross-reference actions. If the Family Health Unity (USF) is not articulated with other health treatment levels in the system, the program will not succeed – a reference action. The same way, after care the patients, the reference hospitals must follow up the PSF sta´ to enhance the quality of the care when the patient is back to the basic care – this cross-reference action needs to be improved. Although is important the existence of ambulances to this stage of the process, they are not available in most USFs. In theory, the program should be a **reorientation of the health care model**, reducing the demand to the hospitals, but in practice what happens nowadays is that the agents are finding diseases that were unknown for the community and since there is no pattern between di´erent USFs, the success about the treatment is not as high as expected.

There is a multi-professional team in each one of the basic units responsible for the attendance of a pre-defined number of families in the community. One USF can have more than one professional team, depending on the number of families connected to the team. The home visit is one form of monitoring the family's health situation – can identify the housing conditions, environmental conditions in which the family is inserted and the morbidity probability based on these aspects. The home care does not replaces the hospitalization, but aims to humanize the treatment and guarantee more comfort for the patient. The PSF has three main guidelines: the *health promotion actions*, the *prevention* *actions* and the *healing actions*. In the (1) **promotion actions**, it can be discussed on personal hygiene habits, water quality, garbage and sewer issues – everything related to the citizen concept. In the (2) **prevention**, it is tracked the diabetes and hypertension cases; the immunization and the prenatal care are done. And in the (3) **healing actions**, there are clinical treatments in medicine and nursery with basic procedures as bandages, nebulisation and injection procedures.

Copque ffi Trad (2005) compared two municipalities of Bahia through three parameters: management, practices and coverage. It seems that there is failure in sta´ training, mismanagement and a high spontaneous demand are the main factors for di´erent PSF outputs. There were di´erences about the management, amount of investment and even the recruitment of the professionals in the two USFs analysed. While in the program A, the professionals were identified through public tender process, with all worker's rights according to the Consolidation of Labor Laws (CLT); in the program B the sta´ were hired by the municipal government and only the nurses had the contract according to the CLT – could be perceived the atmosphere of insecurity and dissatisfaction. The municipality A develops more prevention actions as educational activities group about prevention care and the promotion of the teeth brushing and fluorine application in the community.

Still according to Copque ffi Trad (2005) it is common the scarcity of medicines and medical material (condom, colposcopy and bacilloscopy material), which is an obstacle in the development of educational and preventive activities. It was worse in the municipality B. The authors concluded that the B scenario was closer to the actual PSF situation, in which for the community, the program is only 'one more', far away from its real objective. And they highlight that, when it comes to covering, in order to be a strategy for transforming the health practices, the program must reach the entire population and not only the poor people.

In a research comparing the Basic Care – Traditional Basic Health Units and the Family Health Program Units – of some municipalities from the Brazilian South and North-east, Facchini *et al.* (2006) noticed more professionals in the Traditional Basic Health Units (UBS) than in the Family Health Program (PSF) and more professionals in the South municipalities than in the North-east municipalities. Around 40ff of the sta´

were hired through public tender process in both regions. And almost all UBS have a reception room, although in only 13ﬀ they have infrastructure. The authors state that the PSF is properly functioning in the local health system and represented a successful e´ort to promote equity, since its presence is higher in the poorest regions.

It is a challenge to change an established concept of health care. The Family Health Program is succeeding about the equality objective, according to research, but it is far away from two other program objectives: to guarantee the access of the basic care to **all** citizens and to reorganize the health care practice. To assure the proper investment of the resources is a beginning. Investments in computers to support the completion of paperwork, in the professional team for them to have incentive to work; in the medical folders, so the community can be better educated; investment in the establishment of infrastructure so people can be assisted with dignity. But the guarantee of investments applied is not enough. It must exist a pattern in the actions based on the 'good cases' about hiring the professionals, filling the bureaucracy and the process of assisting the population.

The City Academy is a program created in 2011 by the Ordinance 719, originated in Recife years before, to implement infrastructure poles with equipments and qualified professionals to guide the local population in physical activities and health diary habits. In most of them, there are lectures and meetings related to social and health issues, gym classes and physical and nutritional evaluation by specialized professionals. As a result, it was noticed a reduction in the number of chronic diseases. In the end, its objective is the same as in PSF: to invest in the education and to promote the health in the community.

4.5 Management Actions to Solve the Queueing Issue

There are many ways to tackle the queueing problems, as can be seen in the references.

4.5.1 Procedure Suspensions and Surgical Pathway

There are many sources of variation along the elective treatment pathway and these can a´ect the whole health system. There are natural and artificial variations. It is not possible to control the natural variation because in a hospital there are di´erent patients, di´erent times the patient arrives and di´erent sta´ skills and motivation. The artificial variation is created by the way the system is managed: since the way the services and sta´s are planned until how the clinics deal with priority or urgent cases.

Non-managed artificial variations in surgeries can increase the waiting time for a surgery, which can determine the patient's survival. According to the World Health Organization (WHO), a "Safe Surgery Save Lives". In its campaign, WHO standardizes a surgical check-list to be implemented around the world. The surgical pathway has the objective of reducing in-hospital mortality and surgical complications. It appoints responsibilities and specific checks, standardizing the operative process of all procedures.

Natural variation can be studied to link the identifiable patient characteristics with the di´erent procedures required. This segmentation can increase the quality and quickness of the service. But the 'human factor' causes variation unintentionally, so most of the variation in health-care is caused by how the sta´ make decisions and work in the system. Map techniques, compare journey, the capacity-demand analysis and its variability can provide the necessary information to redesign the pathway procedures. To manage variation is a essential approach to reducing delays in patient care.

The operating theater is one of the most expensive sector of the hospital. A better usage of the available resources in the operating room has direct implications in the hospital e¸ciency. The operating theater is organized with all the material requested to perform a surgery. There is a scrubbing room and there are appropriate and disposable gloves, masks, surgical caps and clothes. After each surgery, a protocol of cleaning and disinfecting is performed. Recovery rooms are located for each patient after the surgical procedure. Lights, air conditioner, nursery team, anesthetist, surgeons and a auxiliary team are also inputs in this model. If there is a broken equipment, for example, after all these resources and professionals allocated for a patient at the same time during the day, the hospital waste time of the professionals, money (because of the resources) and maybe the opportunity to perform the surgery of another patient. The queue in the health system is growing up.

In the other hand, the patient will pass through a psychologic pressure situation to prepare for the surgery again: the fasting, the medications and the anxiety. A pre-operative visit can reduce the anxiety of the patient in answering his/her doubts about the procedure and post-surgery. A check-list to ensure the patient conditions are quite enough to perform the surgery and to guarantee the equipment and material conditions are ready to usage could save some expanses. From the backstage, there is a high complexity quantity of processes to support the surgery action: since the diagnosis by image until the logistics of blood bank, materials and medicines, the reservation of the operating room and the post-anaesthesia room. Maybe all that costs are not so significant if the hospital has **one** surgery suspended, but in scale these costs are disturbing. The pressure for productivity without infrastructure is reducing the usage of the checklists in the public hospitals. The government must understand how the tradeo´ between quality and quantity a´ects the behavior of the professional team and the costs for the hospitals before implementing politics to reduce the waiting lines in the public health sector.

A surgical suspension is only a postponement of a necessary service for the patient recovery. The surgery will have to occur later, unless the patient dies before it. In many hospitals, however, the surgery cancellation is considered part of the routine and inherent to the functional structure of the institution. It harms the hospital, which does not diminish its queues and it harms the patient who had psychological and physical preparation and he will have to do it all over again. It can happens for various reasons: the absence or delay of the surgical team, failure in the communication between these professionals, lack of surgical center or inpatient unit, lack of materials, pre-operative failure, lack of exams, among other reasons.

According to Wyllie *et al.* (1988) an e¸ cient surgical service should have high through-put of patients and a low rate of cancellation. He considers that the main question to be answered is “what could be done to shorten stays without endangering patients?”. The patient cannot be admitted in the same day of the operation because if he did not fasted for the required time, the anaesthesia can be risky. In the other hand, longer stays can increase the probability of hospital infections and deep venous thrombosis; it can also reduce the productivity of the hospital because less people may be attended. It is hard to find an optimum at this balance. Ontario’s hospital already knows the overcrowding will not increase the hospital productivity and may even reduce it. Ontario has the highest hospital occupancy rates of industrialized countries and because of this, the Bristish Medical Journal published a research made with 22 million patients over five years period that found the risk of death and hospital readmission increased with the degree of overcrowding (Coalition, 2011).

To avoid cancellation, the surgical center have to be constantly updated by the inpatient units through a system of communication. It can allow the continuity of the care provided. The notes in the medical chart is not always clear, complete or comprehensible. Technology may help the flow of information in this case. The medical sta´ can use a surgical checklist[3] to reduce adverse events before the surgery. For a good management of the surgical center, there should be a clear, standardized and well structured information to help the decision making. Duarte ffi Ferreira (2006) a¸ rm that these information can be presented in a Balanced Scorecard (BSC), which are financial indicators to show the results reached and takes into consideration all areas of the process including the customer relationship. The BSC can also consider the mortality rates of the hospital and the time of permanence into the hospital, two important indexes for the hospital productivity. All indicators must have simplicity, wide applications and measurability.

The control of the scheduled surgeries can reduce the patient exposure, can diminish the inpatients time, the risk of hospital infection and can reduce the costs of the treatment. For sure the institution will have higher financial revenue, productivity and quality in the health-care for the patients.

[3]A checklist model can be found in `www.surpass-checklist.nl`

4.5.2 Staffing Requirements, Technological Investments and Discipline in the Queues

There are di´erent levels for queueing management:

1. Basic — Establishment of a transparent and democratic order in the queue. The technology used can be the number on your admission pass. Can be used also an electric panel.

2. Intermediate — A database is kept with the queueing statistics information. It is possible to control more than two queues and generate reports.

3. “Pre-management” — It is possible to control di´erent queues and compare statistics data diary, monthly and periodically.

4. Management — The manager can have access to the database through Web and multi-platforms. It is possible to monitor the queue indicators in real time what permits faster decision making.

What is the tolerable limit of time people could wait to be serviced at any time? How large sta´ is required to give adequate service for these people to not wait more than a given number of minutes? The manpower will be calculated based on these decisions the manager must provide. Unnecessary risks can be faced if there is not enough sta´ in a higher workload period. But adding an extra person is not always e´ective as a solution. Sta¸ ng requirement can reduce the patients’ sojourn time and save millions for the hospital per year. The monitoring in real time allows the reallocation of the employees or changes in the priority queues. It is also possible to simulate times and movements with di´erent numbers of sta´.

It is easy to estimate the man-hours required to provide the routine services, but it is not a simple task to estimate man-hours to be allocated to non-routine activities: calls arrive at random and the required time to complete the service is also random, depending on the kind of request. On the other hand, significant under-sta¸ ng of the unit would result in bad costumer service. The administrator must decide which one of several criteria is the most relevant as the basis for choosing the sta¸ ng level (Gupta *et al.*, 1971). For emergency units, although, it is always necessary a higher level of sta´.

To control μ, the manager can capacitate the employees or identify other gaps. The queue management allows the decision maker to create productivity targets for the sta´. Once is stated the sta¸ ng requirements, the manager can invest in technologies to manage the queues demand. Of course the monitoring brings the advantage of homogenize the demand – in observing the less crowded hours, the manager can incentive the clients to use the service at this time and adequate the sta´ as well, it is a queueing discipline management. The use of electric panels, television set and video monitors, opinion meters, biometry and Radio-frequency IDentification (RFID) are more interesting and appropriate in the technology context of queueing management.

There are restaurants in which you can put your name on a list, take the beep and go out of the establishment to solve other problems or walk around in the mall. People are in queue but not su´ering with the physical and phycological issues about the waiting. Some hospitals use beep and pagers to communicate with patients in the transplant queue. New technologies allows one to buy the tickets and check the menu in a restaurant through internet. Maybe the health sector could use these mechanisms to facilitate the management of the diverse queues in the system. The internet has an important job in the queueing optimizations. In Florianopolis emerged a di´erent solution for this same problem: the Web-page (`www.guardafila.com`) allows people to emit the number of the admission pass after register the cellphone number, so the person can receive a message when his number is close to be called in the queue.

In the airport queues, there is a clear division between the queues for people who did the check-in earlier (in the internet, mostly) and who did not. All the information is clear in the television set and video monitors (flight times, company queue, type of queue and information about the airplane) and the motivation for people to do check-in earlier is also clear: shorter queues, faster service. The self-service in a separate space reduce the time in the queues to deposit the baggage, it is a pre-service. The hospital could use the same transparency in the receptions, it reduces the anxiety of those who wait and an appropriate pre-service can facilitate queueing discipline in the procedures.

In the supermarkets, we can see the bar code in every product, a mechanism that facilitates the dynamics in the cash register reducing the waiting time of clients. Nowadays there is the Radio-Frequency Identification, a method of automatic identification of radio signal. It is possible to recover information and store data remotely through this device. This technology permits the data interchange between labels and chips or transponders which transmits the information by an induction field. In a supermarket, for example, would be possible to pass with the shopping cart full of products and know at the same time the amount of money should be paid for all products. In Hospitals, the RFID has been used to real-time patient management. The Albert Einstein Hospital in São Paulo, installed the first phase implementation of the RFID — the monitoring of temperatures in refrigeration units and the tracking of the assets.

Biometry is a common-place in many establishments. Hospitals use it to tracking the entrance of the employees to work. It allows the controlling of authorizations in di´erent rooms and of the working schedules compliance. The biometry can be based on di´erent parts of the human body: fingerprints, the palm of the hand, iris or retina of the eye, among others less e¸ cient solutions. Each one has its costs and advantages. The restaurant in the Hospital da Restaura%ão uses the fingerprints to control the number of meals served per hospital department. Other technologies could be used to reduce the restaurant queue. The manager only have to decide the amount of money he is willing to pay.

5 A CASE STUDY: THE HOSPITAL DA RESTAURAÇÃO IN RECIFE

The Hospital da Restauração is a very important hospital in the Recife Metropolitan area.

5.1 The *Hospital da Restauração*

THE *Hospital da Restauração* is a reference unit in general surgery, trauma and orthopaedics, vascular surgery, neurosurgery, neurology and maxilla facial surgery. With forty years of existence, since 2002 all the treatments in the Hospital is made by the Unique Health System (SUS). The Hospital treats severe traumas and multiple traumas as traffic accident, fractures, aggressions by weapons and firearms, severe burning cases, patients from other hospitals and unconscious patients with risk of death.

The *Hospital da Restauração* has 699 beds registered in the Health Ministry, but including the extra beds, it is a total of 723 beds to meets its demand. Since June of 2010, the old General Emergency is divided into three emergencies with independent entrances and infrastructure: Pediatric Emergency, Traumatology Emergency and Clinical Emergency.

The Burn Treatment Center at the Hospital da Restauração is a hospital within a major trauma hospital. It has a specialized team of 14 physicians (plastic surgeons, general surgeons, clinicians and pediatricians), physiotherapists, occupational therapists, psychologists and all nursing staff: nurses, nursing technicians and stretcher bearer. The sector also has, daily, two anesthetists for surgical procedures such as debridement and dressing, and for the repair surgeries at own sector of operating rooms.

The hospital has been innovating about administration of the system. In 2008, it created the Management of Waste Sector and had an economy of R$ 38,397.46 with the cremation of infected residues. Concerning the rehabilitation of the patients, the Hospital implemented a respiratory physiotherapy in the Emergency Clinic, Trauma Unit and Anaesthesia Recovery room, which has been reducing the mortality of the patients and decreases the time spent in these sectors. Monthly, the hospital receives 2.2 thousands of hospital admissions, 800 surgeries, 10 thousands of emergency attendance and 13 thousands ambulatory attendance. All information about the Hospital can be found in the HR website or in the website of the State Secretariat of Health.

5.2 The Queues in the Elevators, Parking Lot and Restaurant

With more than 3,500 employees and 400 companions distributed between four shifts and nine floors, the hospital has a limited infrastructure for parking lot, elevators and the restaurant. With an arrival rate higher than the service rate, it is inevitable the existence of queues.

There is a tra¸ c of more than 3,000 people in the hospital everyday and it is only 150 vacancies in the parking lot in front of the hospital in which 90 are reserved. So it is normal to spend more than 20 minutes waiting on the queue in the entrance of the car park. Since there is no way to increase the capacity of the parking lot in a short-run without disturbance, the hospital's director 'rents' a space next to the hospital to hold the demand for the hospital parking lot, mostly the employees.

The flow of the employees within the hospital can su´er a little bit if they try to use the elevator at the lunch time which is even worse if the restaurant queue is large. There are three staircases in the hospital: the north one, for garbage and food; the south one, for emergency and the social stairs. But the staircases are under-utilized. There are 6 elevators of which two are for employees and visitants, two are for beds transportation and the other two are for the transport of the food for the patients, the hospital garbage and the companions tra¸ c. And at least on the first two (in the entrance of the hospital) there is always queue.

Whereas the hospital is a non-stop service, the contract with the restaurant – specially to serve the patients – attends the hospital employees and also the companions, with no prejudice to the patients recommended nutrition, a priority. It makes the hospital employees save time and considerable reduce the waste caused by the displacement to have the meal. The restaurant has 232 seats and there are eighty employees working in the kitchen to prepare 1,500 meals. There is space for eight trays in each ramp, where stays the food. The queue at the restaurant can harms the image of the hospital and this should not happen because while there were many people waiting outside of the restaurant, there was an average of 40ff of the restaurant seats empty. Figure (5.1) shows the layout of the restaurant where it is possible to see how the queues a´ect the activity in the ground floor of the hospital.

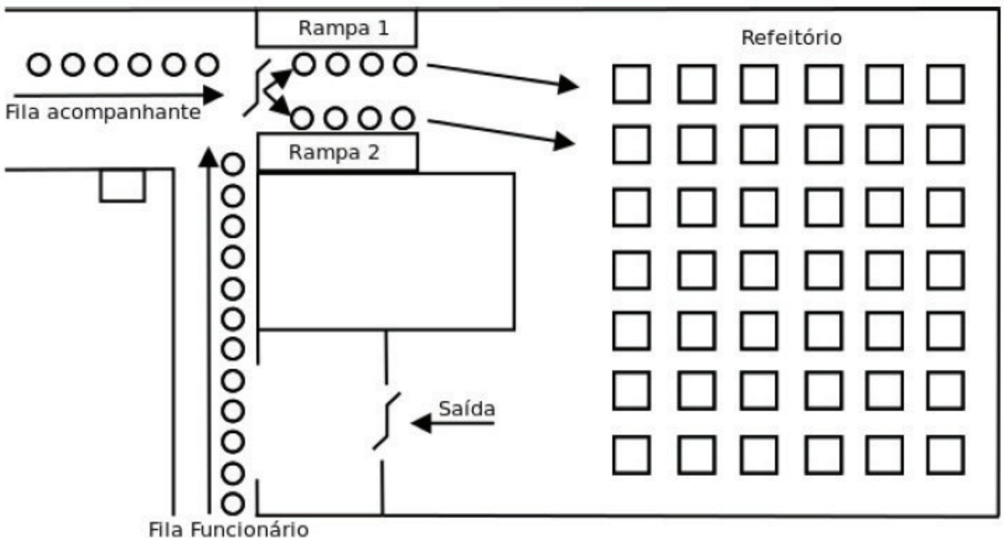

Figure 5.1: Restaurant Layout

5.2.1 The Research

To have a previous knowledge about the situation of these queues in the Hospital, a survey was applied with the users of the restaurants, essentially employees and the patients companions. Students of the Probabilistic System Discipline went to the Hospital to apply the survey in 14 of November of 2011. To verify the information provided by the hospital's employees, the students measured the time spent in the restaurant queue in the 16th and the 17th days of the same month.

The first survey (Survey I) was done with the employees of the Hospital about the queues in the parking lot, the restaurant and the elevator. And the second 'survey'

(Survey II) was the timing of the queue of the Restaurant. For the first survey, the pilot questionnaires were made by the employees but it had few problems related to the opened questions. So interviewers were needed to reduce the error problems. The survey I was applied again after the few months to know if the Hospital employees noticed any change in the restaurant queue dynamic (Survey III).

The data collection about the timing in the Restaurant queue was done between 10.30am and 3pm - the busiest part of the day - during two days. The time was noted as each client entered on the queue, requested the service, passed in the turnstile, and also when the client departed from the restaurant. The di´erence between the latter two steps was defined as the service time.

Instructions to the interviewers

The instructions followed by the "interviewers" when measuring the time were:

1. To synchronize their clocks;
2. In general, the first client arrives at the queue at 10.30am. It is necessary more than one person to take note of the time because the arrival rate is high;
3. The time the client begins to pass at the turnstile should be noted. It is when the client is authorized to put the finger at the sensor or to pass the card at the turnstile. In most part, the client stays waiting for the ramp to be empty. The person to take note of this time has to be inside of the restaurant;
4. The time of arrival at the ramp it is when the client takes the first apparatus, typically the tray;
5. At least two people are needed at the end of the queue;
6. In the exit must also have at least two people. Once registered the time the client went out, after the devolution of the tray and cutlery, the form goes to the urn for the lottery be realized;
7. Activities should go on until 3pm.

5.2.2 A *Status quo* of the restaurant queues at a first glance

The scenario observed at first in the queue – before any research or intervention – is listed below.

- The average time to wait in the restaurant queue on lunch time was 40 minutes
- The average time to pass in the turnstile was one minute
- The average time to go from where the person takes the tray and plate to the end of the 'meal in the tray' it was at minimum 4 minutes
- The total time spent just before people start to eat it would be around 45 minutes. Which demands a lot of patience
- 40ff of the vacancies inside of the refectory are idle

Negative comments about the waiting are frequents. Theoretically, more people should be able to eat at the hospital restaurant. It is almost 1,200 employees and 400 companions who could take advantage of this benefit. There is no bottleneck on the kitchen about the amount of meals could be prepared. The problem is the speed.

A little early before the employee's lunch – around 11am – arises considerably the flux at the elevators, because the employees are going to the restaurant queues. It arises the length of the elevator queues in all floors. The formation of the line of the companions starts long before the restaurant opening – at 1.15pm there are companions on the queue, but the restaurant opens for them at 2pm. The queue of the employees ends at 2pm, and the exit of these ends at 2.45pm approximately. The elevators queues grow, because people go back to their work place while the companions is going down to the restaurant. The companions have positive e´ect on the recovery of the patients and it is important for them to have what to eat in the restaurant hospital because many of them live at the countryside.

Plenty solutions could be considered, but the system has to be thought as unique. Everything is connected: turnstile, to put the meal on the tray, table occupancy, kitchen, elevators.

5.2.3 The Survey — General Considerations

Most people ask why to begin the study with a restaurant queue. What about the medical queues? The answer is simple: everybody should understand the importance of the study of the queues, not only the administrator of the system, but also the employees and any other stakeholder related to the queue. After they see the e´ect of the queue studies, it is easier to apply any change in the other queues of the system. And more, there are costs related to the restaurant queue that a lot of people do not see.

After more than twenty minutes waiting for the service, the employee gets fatigued, restless and maybe he will spend more time eating than the usual to feel the justice about the waiting time, to worth it. For sure he will be back to the o¸ ce less productive and it will a´ect his service to the final client of the system – the patient.

The hospital is paying for this time the employee spends on the queues. So, the more time they wait, higher is the prejudice of the hospital. To have an idea, if a person works eight hours per day, he spends 33ff of these 8 hours of his work-time in the queue, which means he has 4.125ff of his day idle. If it is considered a medium salary of *R*ı 800 there is a monthly lost of *R*ı 33 per employee per month. It seems not much, but since 850 employees at minimum have lunch on the restaurant, it is a damage of *R*ı 28, 050 per month, and Rı 336,600 in a year. This money could be invested in hospital equipments or in a career planning to improve the motivation of the people who work at the hospital.

The queues make people change the habits to avoid the waiting line. In the hospital, people started to bring foods – lunch-box – to eat in the lunch time because of the long waiting on the restaurant queue. Then, as long as more people acquired this habit, they started to buy electric machines to conserve the food and to heat the food. Now, it is not hard to find electric equipments for personal use in the hospital o¸ ces like sandwich toaster, liquefier, small fridge, microwaves and an electric water heater. These overload the electric system and creates a contaminated environment for the Hospital. To eat inside of the hospital in a non-proper place, as the restaurant, can increase the probability of hospital infection and for sure causes the proliferation of germs, cockroach, ants and maybe rats. A better operation of the restaurant can eliminate this bad habit.

5.2.4 Analysis and Conclusions

Some considerations about the restaurant queue in the hospital da Restauração (estimated values).

The Employees Queue

- arrival time: $\lambda = 4$ clients per minute before the survey
- service time: $\mu = 0.2857$ clients per minute in each ramp
- average number of meals: 750 before the survey, more than 800 after the survey
- average time to wait in the queue: 40 minutes before survey, 20 after
- numbers of seats in the restaurant: 232
- numbers of idle seats while had 80 people waiting on the queue: 93 idle seats

Companions Queue

- arrival time: $\lambda = 5.1$ clients per minute before the survey
- service time: $\mu = 0.2857$ clients per minute in each ramp
- average number of meals: 250
- average time to wait in the queue: 40 minutes
- numbers of seats in the restaurant: 232
- numbers of idle seats while had 102 people waiting on the queue: 93 idle seats

With $\lambda > \mu$ it is impossible to manage the queue. Lots of losses. Here are presented some results of restaurant queue analysis for the first two surveys.

The graphs and analyses show that the database is robust, meaning that the number of interviews collected is large enough to present the profile of the sample and to report the employees behaviour with respect to the hospital queues. The database follow the the beta distribution (Vencelaus *et al.*, 2011).

A descriptive analysis was performed to expose the results achieved. The variables measured are presented through charts or graphs including also the use of some descriptive measures such as minimum, maximum, mean and standard deviation. For the correlation analysis it is used the Spearman correlation coe¸ cient, because it allows the work of ordinal variables in the study setting. To check if two independent groups come from the same population, it is used the Mann-Whitney test, which is a nonparametric test (when there is no assumption of normality) alternative to Student's t test to compare the means of two independent samples. And for the variance analysis is used the Kruskall-Wallis test, the non-parametric version for the F-test. All conclusions were based on a significance level of 5ff .

The Hospital da Restauração has nine floors:

Ground floor: Laundry; Laboratories of Clinical and Pathology Analysis; Restaurant; Blood transfusion and collection.

1st floor: Adult and Pediatric Emergency.

2nd floor: Burn Treatment Center; Adult and Pediatric ICU; Pharmacy and Warehouse.

3rd floor: Surgical Block (11 operating theatres).

4th floor: Pediatric Ward.

5th floor: Neurosurgery Ward.

6th floor: Oral-maxillofacial, orthopedics wards; Plastic surgery and Neurology ICU.

7th floor: Vascular Nursing and Clinical Overview.

8th floor: Neuro Nursing and Clinical Medicine.

9th floor: Directors, Managers, Library, Home, Server and System Information.

The *survey I* explores the perception of the employees about the queues they used to face everyday, the situation nowadays is a little better. It is analysed here few characteristics of the survey questionnaire applied.

With the question 12 of the *survey I* (below) is possible to distribute the employees acrosss di´erent time intervals.

12) In which floor do you work? Ground floor(0) ☐; 1º ☐; 2º ☐; 3º ☐; 4º ☐; 5º ☐; 6º ☐; 7º ☐; 8º ☐; 9º ☐

The first survey was applied in di´erent floors of the hospital under the guidance of the hospital engineering. 323 surveys were applied in one day. The figure 5.2 shows the di¸ cult of applying the *survey I* at the *3rd* floor, because of the surgical dynamic. In the second survey, the students were spread along the restaurant queue to distribute the form among the employees to be filled with the timing information. A number of 1058 questionnaires were filled in these two days. The figure 5.2 also shows the distribution of the employees per floor during the time measured (*survey II*). Di´erent from *survey I*, the ground floor is significantly represented (histogram on the right).

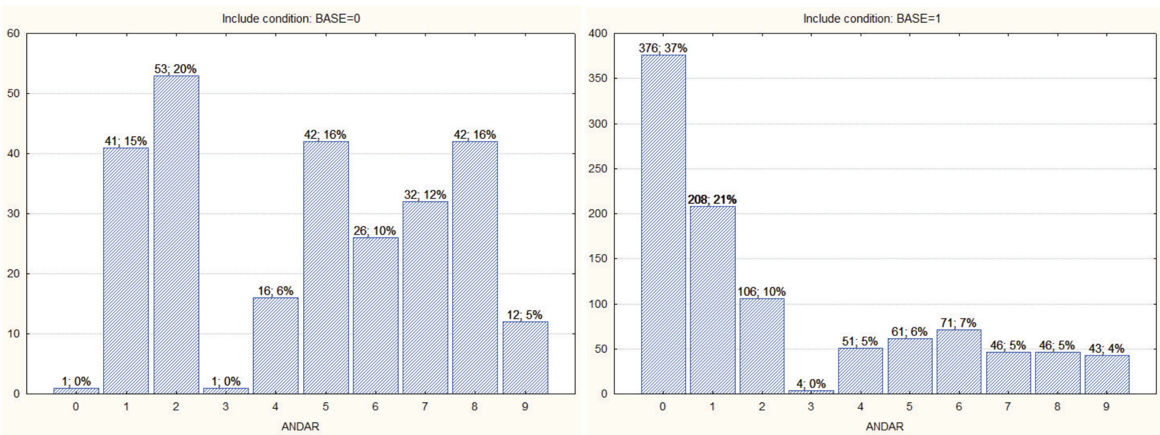

Figure 5.2: Distribution of the employees per floor – Surveys I and II.

The variable HCHFILALMOCOCAT is the range of the arrival times categorized. The classification follows:

1rst class: Before 10h30 until 11h

2nd class: Between 11h and 11h30

3rd class: Between 11h30 and 12h

4th class: Between 12h and 12h30

5th class: Between 12h30 and 13h

6th class: Between 13h and 13h30

7th class: Between 13h30 and 14h

The figure (5.3) presents a Box ffi Whiskers Plot, a graph that represents the interaction between variables and a categorical variable. The graph creates a box around the means to show a chosen range, there is a line crossing the box (whiskers) that is a measure of variability and represents the range of the variable. The figure (5.3) presents the time people wait in the restaurant queue based on the time they arrive at the queue. The Kruskall-Wallis Test ($p < 0.01$) is significant and, therefore, there is statical evidence that the employees who arrive earlier (between 10h and 11h30) in the restaurant queue, wait more.

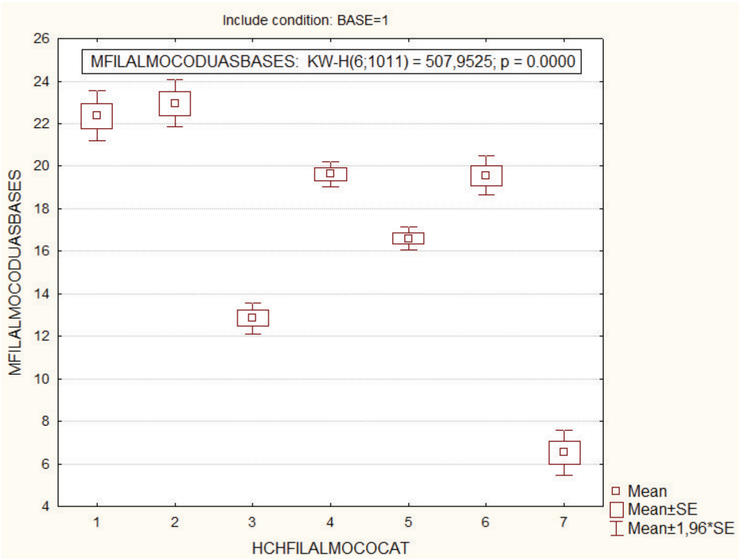

Figure 5.3: Waiting time in the lunch queue per arrival time.

The di´erence in the distribution of the two surveys in the figure (5.4) indicates that the perception of the employees about the time interval they arrive in the restaurant queue is di´erent from the time they actually arrive. And from the figure (5.5), there is di´erence statistically significant (Kruskall-Wallis Test, $p < 0.01$) between the two groups. People arrive earlier than the time they stated.

The figure (5.6) shows the probability distribution of the hospital employees during the two days of time measurement (*survey II*). The *valid N* for the first day of time measurement was 563. The employees arrival is well distributed between 11h and 13h30. The *valid N* for the first day of time measurement was 495. The arrival in the queue is

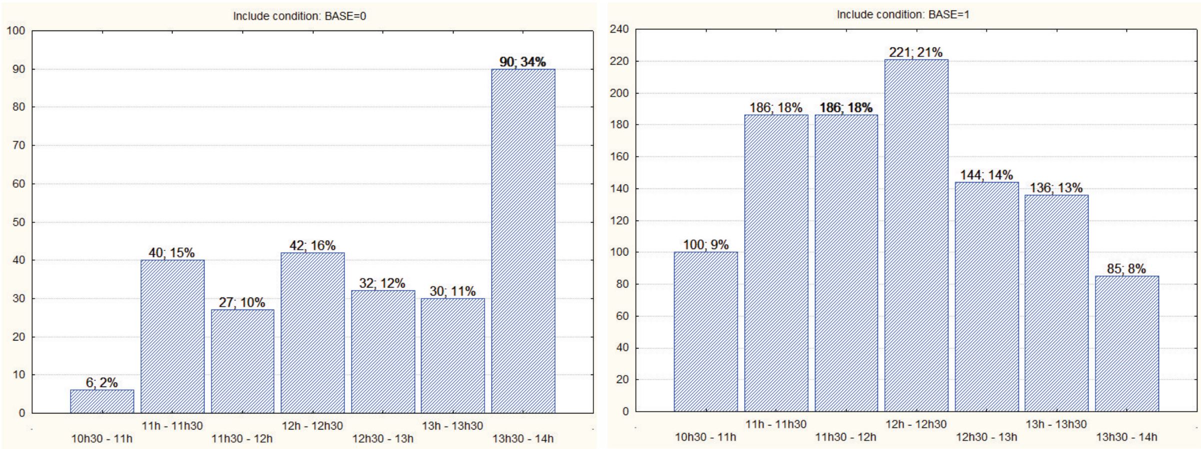

Figure 5.4: Distribution of the employees per arrival time – *Surveys I and II.*

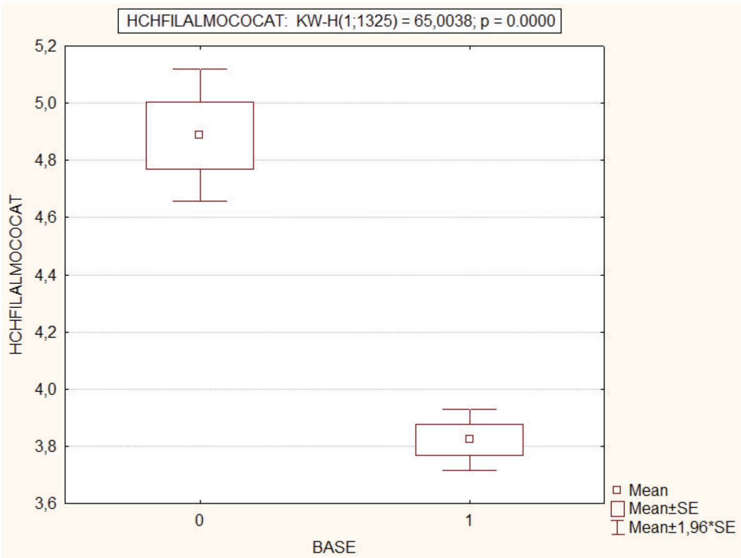

Figure 5.5: Arrival time *Survey I* vs Arrival time *Survey II.*

spread out along the lunch time with a peak between 12h and 12h30. A larger sample would be necessary to describe the queue behaviour and to analyse the seasonality.

Comparing the two days of data collection, the figure (5.7) presents the di´erence between the arrival time means, the Chi-square test is significant ($p < 0.01$) and indicates that the variables are associated and that the frequencies vary across the days. People arrived earlier in the restaurant queue on the first day of sample.

The table (5.1) shows the descriptive analysis of the waiting time on the restaurant queue categorized per arrival time. There is an outlier (Maximum value of the variable = 86) between 11h and 11h30. For some reason, a person who arrived this time waited for one hour and 26 minutes, increasing the variance of the time classification. The higher

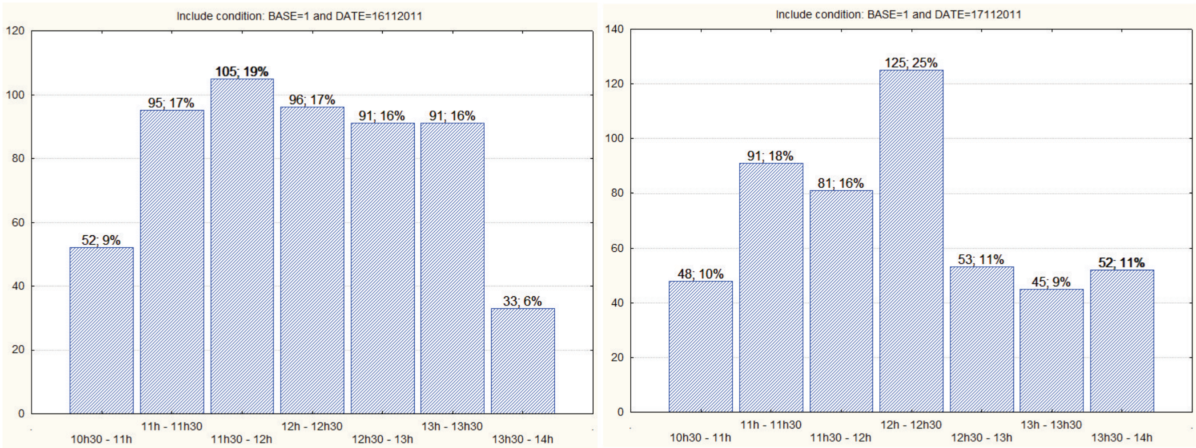

Figure 5.6: Distribution of the arrival times – Survey II, Days 1 and 2.

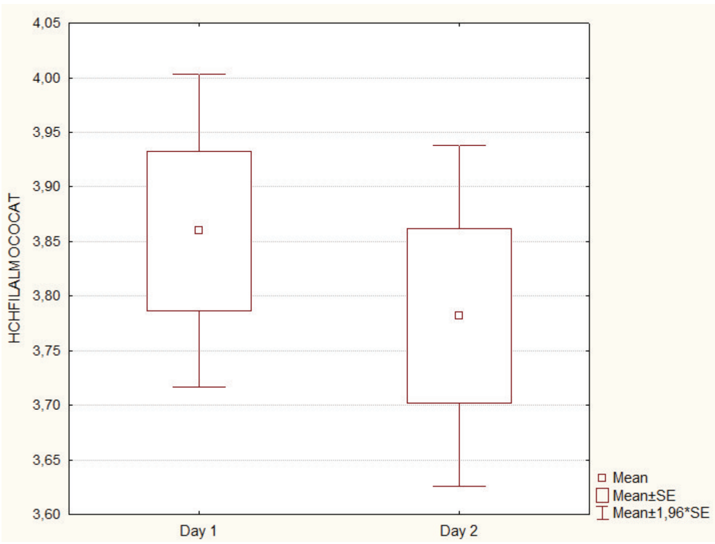

Figure 5.7: Arrival times Day 1 vs Arrival times Day 2 – Survey II.

average waiting time is for the people who arrive between 10h30 and 11h30 ($p < 0.01$ for the Kruskall-Wallis test).

The table (5.2) shows the descriptive analysis of the time spent in the ramp. It is possible to observe that people can spend until 26 minutes to serve the meal in tray. It is a long time considering that there are people who spend less than a minute. Indecision about which meal to ask, the ramp to take (there are two) or just the need to spend more time choosing what to eat to feel the justice about the time wasted waiting in the line are possible explanations for this phenomenon.

On the second day, the interviewers heard the employees commenting about the speed along the ramp, considering the day before. To verify if there is di´erence among the

Table 5.1: Time spent on the queue classified per arrival time.

Arrival Time	Valid N	Mean	Minimum	Maximum	Std Dev
$10h30 < x \leq 11h$	126.00	22.12	4.00	39.00	5.99
$11h < x \leq 11h30$	160.00	22.95	1.00	86.00	7.74
$11h30 < x \leq 12h$	185.00	13.41	2.00	28.00	3.36
$12h < x \leq 12h30$	205.00	19.76	0.00	34.00	4.38
$12h30 < x \leq 13h$	138.00	16.61	8.00	25.00	3.19
$13h < x \leq 13h30$	122.00	19.57	3.00	53.00	5.40
$13h30 < x \leq 14h$	73.00	5.88	0.00	25.00	3.81

Table 5.2: Descriptive analysis of the time spent in the ramp classified per arrival time.

Arrival Time	Valid N	Mean	Minimum	Maximum	Std Dev
$11h < x \leq 11h30$	149	3.30	1.00	26.00	3.06
$11h30 < x \leq 12h$	183	2.41	0.00	6.00	1.22
$12h < x \leq 12h30$	154	2.40	0.00	6.00	1.26
$12h30 < x \leq 13h$	171	2.98	0.00	14.00	1.71
$13h < x \leq 13h30$	116	3.64	1.00	8.00	1.24
$13h30 < x \leq 14h$	140	2.52	0.00	7.00	1.45
TOTAL	919	2.85	0.00	26.00	1.86

average time spent in the ramp between the two days of data sampling, the Mann-Whitney test was done. Also known as the Wilcoxon-Mann-Whitney test, it is a non-parametric test where the variables can have any distribution, and the assumption is that the variables are ordinal or numerical. The test evaluates if the samples are statistically di´erent. The test confirmed that in the second day the time spent in the ramp was lower ($z = -20.752$, $p < 0.01$).

About the total time spent in lunch per arrival time in the queue, it is possible to notice in the figure (5.8) the huge range for the ones who arrived earlier (first class, before 11h). On the average, people spend between 30 and 50 minutes (waiting, serving and eating).

The figure (5.9) shows the positive correlation between the arrival time and the exit time, since the pattern of dots slopes from lower left to upper right. It is just to confirm the consistency of collected data.

The figures 5.10 and 5.11 show the di´erence between the waiting times stated (*Survey I*) and measured (*Survey II*). The question 18 and 19 allows one to identify the employees perception about the time spent in the queue and the time spent eating, respectively.

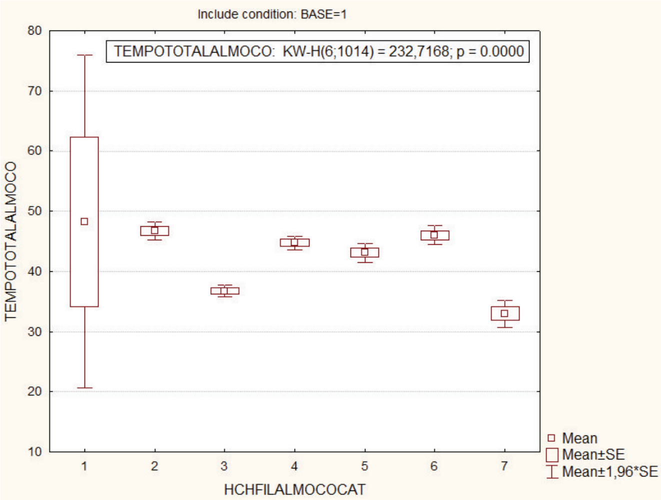

Figure 5.8: Total time spent having lunch vs Arrival time.

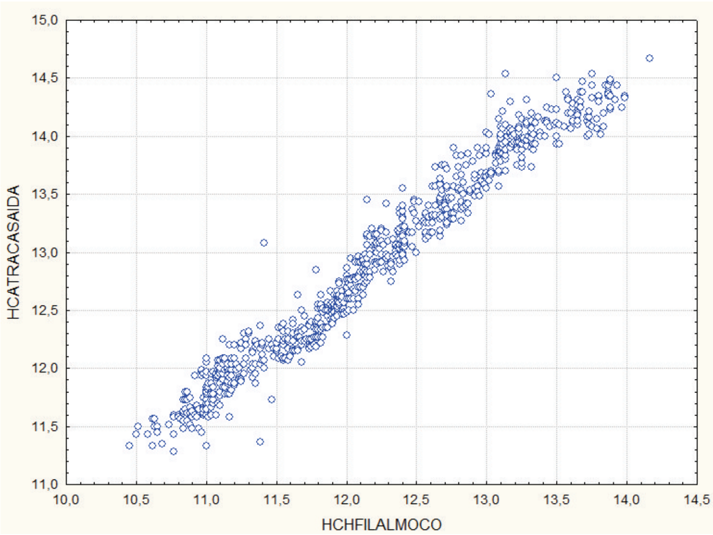

Figure 5.9: Arrival Time vs Outgoing Time.

18) How much time do you wait in line at the HR restaurant at lunch?

19) How much time do you spend having lunch (eating) at the HR restaurant?

The figure (5.10) shows that in the waiting line the time seems to pass slower than it really is.

The measured time is much lower than the perceived time. Whereas the used time seems to pass faster (figure 5.11). It confirms the Maister's theory, that the anxiety makes

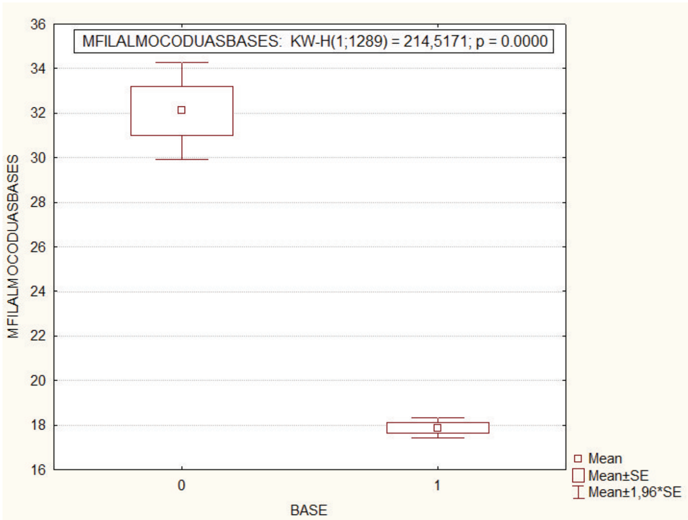

Figure 5.10: Comparison between *Survey I* and *Survey II* for the waiting time.

waits seems longer. When waiting to enter at the restaurant, peckish, people perceive the waiting time slower and, after served, the time is more pleasant and people do not realize how much time they spend at lunch.

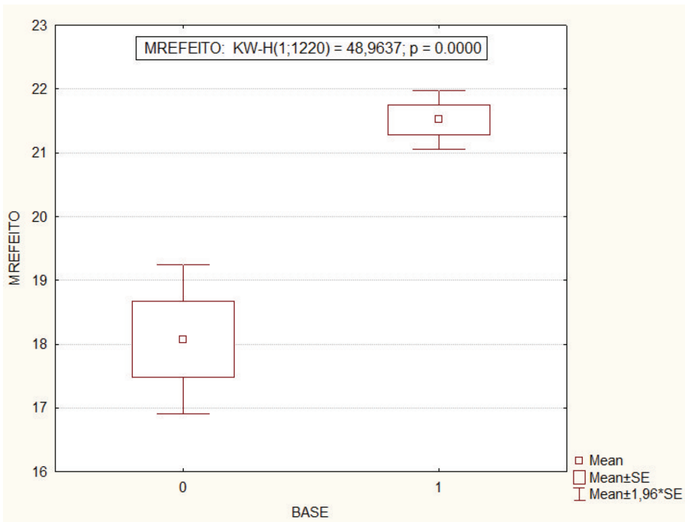

Figure 5.11: Comparison between *Survey I* and *Survey II* for the time spent at lunch.

Elevator queue, parking queue studies, other analysis and results can be found in (Campello de Souza, 2011) and (Vencelaus *et al.*, 2011). The research made in November of 2011, had some results for the hospital. The actions suggested were implemented and has been presenting results for the hospital. The hospital installed another turnstile on the entrance of the restaurant and managed the demand. To reduce the queues it is required to increase the productivity in the ramps (μ) and now with five and four restaurant sta´ working in each ramp to serve the restaurant clients all the time, the queue visibly decreased.

To improve even more the e¸ ciency of the queues in hospital restaurant, the managers should supervise the restaurant operation with cameras and an automatic information system, so the productivity can be measured.

5.3 Surgical Cancellations

Surgical cancellation causes financial losses for the hospital, delay in surgical planning and also injury to other patients, who wait for the operation. It reduces the hospital service rate (μ), increasing the waiting line in hospitals. This section analyses the Hospital da Restauração surgical cancellations, or suspensions, of the elective surgeries.

The Hospital da Restauração provided a sample of the surgical cancellations database from September of 2011 until September of 2012. At first, it can be observed that there is no pattern in the input of the data, which can harm future works to reduce the incidence of surgical suspensions. Historical database in hospitals is a general problem around the world and it happens because the professionals involved in the data entry and in the filling of the protocols do not understand the importance of these information to improve their work.

The regular working scheduling of the operating theatre is from 7.30am until the end of the night. There are 11 Operating Rooms (OR). Three of them for urgency cases and eight OR's for the elective surgeries, these last separated by specialties and scheduled by a surgical chart. All rooms are prepared with the same surgical equipments. At the end of each surgery, cleaning and sterilizing protocols must be followed by the Material and Sterilization Center. These procedures take about fifteen minutes for a regular surgery and at maximum thirteen minutes for heavily soiled surgeries. There are one floating auxiliary sta´, one nurse on duty and one diarist nurse per shift for all operating theatres. The auxiliary sta´ is a scarce resource to the surgical management.

In the period analysed, the Hospital performed a total of 14,862 surgeries. Most of them were Burning surgeries: 6,246; 43.24ff of the total. The secondly most performed surgeries was the Neurology sector, 16.32ff of the surgeries performed in the Hospital. The Neurosurgery is also the first place in surgeries cancelled. Traumatology comes next, 13.13ff of the total and secondly in the surgeries cancelled (26.34ff). It was cancelled 2,645 of the 14,862 surgeries scheduled in this period, a cancellation rate of 17.79ff.

There are nine surgical specialties in the Hospital da Restauração. The table (5.3) presents the percentage of surgeries performed and surgeries cancelled of each one of the medical specialties in the period of September of 2011 until September of 2012. The statistics presented here is a description of the database hospital scenario. Since the database is not organised to facilitate the analysis, it does not correspond to the reality of the hospital. To maximize the numbers of patients attended, the hospital allocates three patients for one surgery. If, somehow, the patient does not have clinical conditions or the equipment for that specific surgery it is not available, other patient can do the surgery. The numbers presented in table, then, does not reassemble the hospital reality but the hospital database situation.

Table 5.3: Surgical Specialties in Hospital da Restauracão.

Specialty	Surgeries performed (%)	Surgeries cancelled (%)
Burn Treatment Center (BTC)	43.24	0.00
Neurosurgery	16.32	38.11
Traumatology	13.13	20.98
General	9.76	14.52
Pediatrics (PedSur)	8.41	1.25
Vascular	5.55	16.94
Oral and Maxillo-Facial (OMF)	2.79	4.84
Plastics	0.71	3.36
Ophthalmologist	0.09	0.00
TOTAL	100.00	17.80

From the 2,645 cancelled surgeries in the period of September 2011 until September 2012, it is analysed here a sample of 1,648 provided by the hospital from its database. The figure (5.12) presents the percentage of each clinical specialty in the sample. And the figure (5.13) presents position and distribution of the data. Neurology and Traumatology are the specialties with more cases of surgical cancellation.

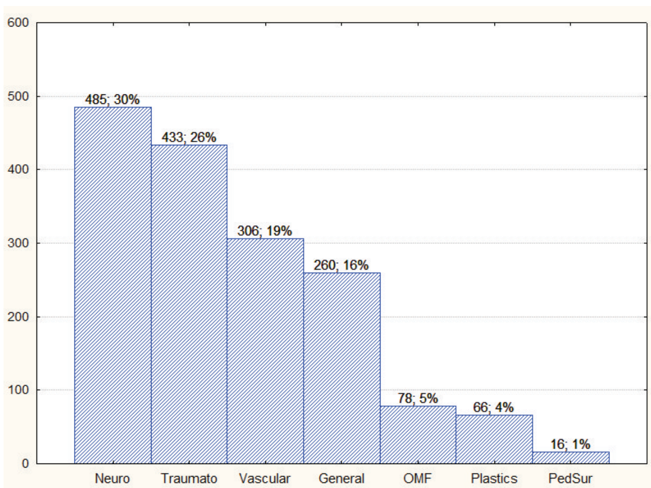

Figure 5.12: Surgical Cancellations of the HR by Medical Specialties.

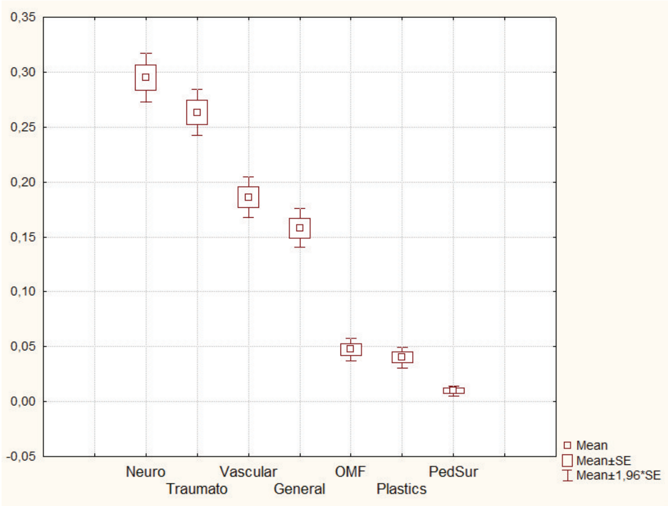

Figure 5.13: Box Plot of the Surgical Cancellations by Medical Specialties.

From the total database, most part of the suspended surgeries happened on Monday (figure 5.14). To demonstrate the statistical di´erence of Monday, ahead of other weekdays, the figure (5.15) presents the di´erence among Monday, Tuesday and Wednesday, and Thursday and Friday. The variables were created from the figure (5.14), clustered. Since Monday is a single variable, not a combination of two days as the others, it needed to be duplicated to maintain the homogeneity (first red box-whiskers). One of the possible explanation for the high number of cancellations on Monday is the extension of weekends emergency surgeries.

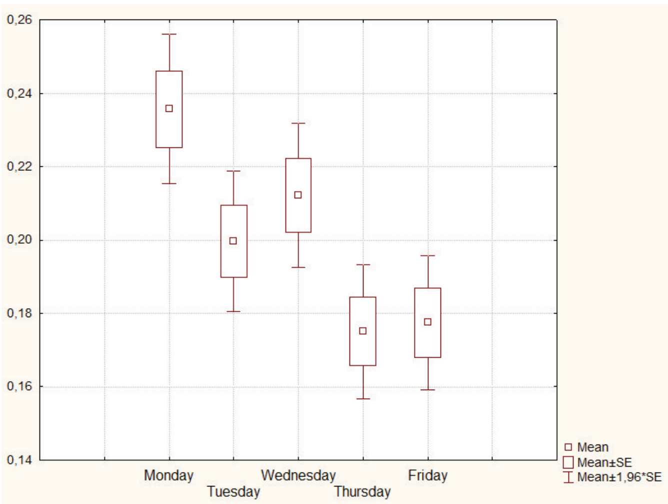

Figure 5.14: Surgical Cancellations of the HR by Day.

It is expected for the major reason for surgical cancellation to be the unavailability

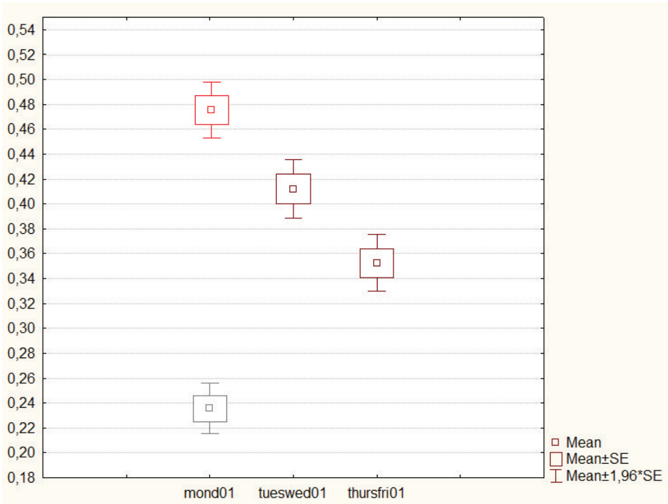

Figure 5.15: Surgical Cancellation Days Clusters.

of anesthetist for all medical specialties, because it is a structural situation in the Pernambuco's Health System. With 37.02ff of the cancellations, it is a really significant problem. Then it is important to observe the incidence of other reasons in the ranking. Through interviews could be analysed the hospital sta´'s perception. According to them, the major reason of cancellation, after the unavailability of anaesthetists, is the *priority to an urgent surgery*. The figure (5.16) shows that this reason for surgical cancellation is not the second, but the 9th reason. And the figure (5.17) demonstrates the possible division of the cancellation reason, according to the distribution. The unavailability of anaesthetists was not considered to better verify the distribution of the other variables; it belongs to the first group. To analyse the reason per medical specialty, the first two groups were considered because of their higher frequencies.

Lack of surgical material/equipment is the second largest reason of surgical cancellations in this period. To deeply understand the information presented in this database, it is demanded more information and only the hospital can explain most of them. This work only intend to point what numbers say, not explain them. The reason "suspended by the surgical team" does not elucidate why the surgery was cancelled, it is a classification empty of information. Problems in the data entry can also be observed in the number of missing data (10.2ff of the total). The hospital maximizes the ORs usage by allocating three patients for the same surgery schedule. It considers that if for some reason the first patient cannot be operated, one of the two others can be operated. The blood is only

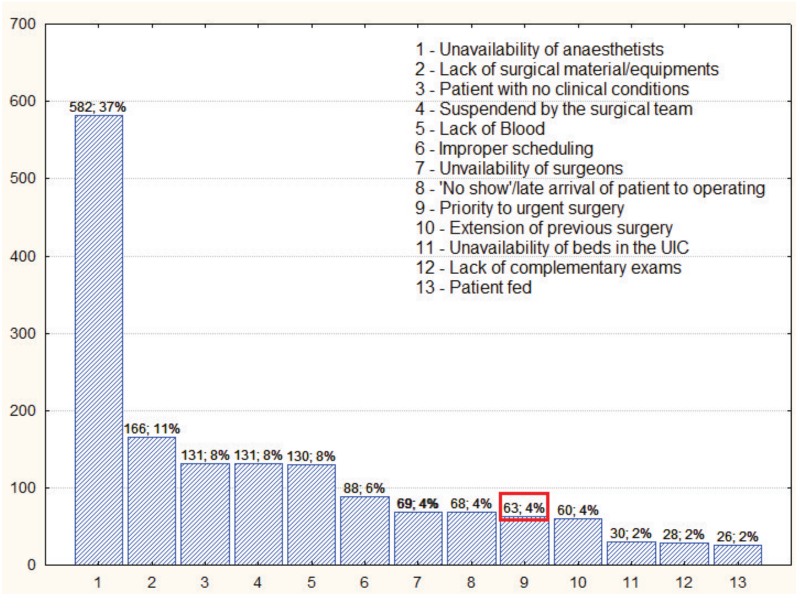

Figure 5.16: Surgical Cancellations of the HR by Reason.

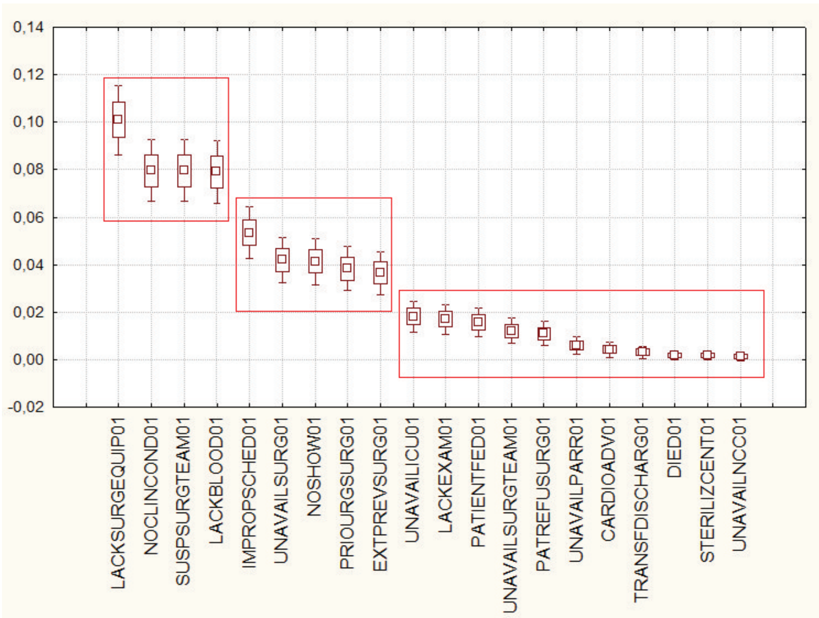

Figure 5.17: Surgical Cancellation Reasons Clusters.

booked for the first patient, a reason to why the number of surgeries canceled by lack of blood is high. Surgical materials are ordered as it is necessary because of bureaucratic and storage reasons. A percentage of the cancellations (19.3ff) could be avoided with a visit before the operation procedure: patient with no clinical condition (131 cases in a year) and patient fed (26 cases in a year). An extra nurse to do the pre-exams and track the patient schedule should be hired.

A highlight must be done for the cases in which the surgery was cancelled because of an error in the scheduling (IMPROPSCHED). It happens because the hospital does not have an Enterprise Resource Planning (ERP) or a Balance Score Card (BSC) as recommended by Duarte ﬃ Ferreira (2006) to integrate all required information about the patient at the same platform. So the surgeries were cancelled because the patient was transferred or discharged (5 cases in the period analysed), dead patient (3 cases), surgery already performed (57 cases) and patient without surgery recommendation (20 cases) are all victims of the lack of simultaneous information and internal control.

The lack of anesthetists is a systemic problem in the Pernambuco's Health System. But a considerable number of the surgical suspensions is due to the surgical team in the hospital (89 cases in a year; 5.41ﬀ). Further analysis must be done to a¸ rm if these cancellations could be avoided. The "lack of blood" seems to be a planning problem of the surgical team: physicians ask to the blood bank smaller quantity than the amount will be necessary in the surgery. The hospital is aware about this situation and it will take the appropriate actions to solve the case. It is a planning issue.

Analysing the reasons of cancellations in the Neurosurgeries figures (5.18) and (5.19), it can be noticed that the second most common reason in the period was the lack of surgical equipments/materials. The surgical cancelled to prioritize more urgent surgery was only 5ﬀ of the total (23 cases in a year). The graphs are equivalents.

In traumatology surgical suspensions (figures 5.20 and 5.21) only 2ﬀ (6 cases in a year) was cancelled because of a more severe case. Highlights for lack of blood (15ﬀ), lack of surgical materials/equipments (14ﬀ) and unavailability of surgeons (12ﬀ), the three main causes of surgical suspension in this specialty after the unavailability of anaesthetists.

The perception of a higher number of surgeries cancelled because of an urgent surgery is truth for the vascular surgeries (figures 5.22 and 5.23).

An interesting observation is that 20ﬀ of the general surgeries (figures 5.24 and 5.25) was suspended because the patient did not show up.

The number of reasons of the surgical cancellation vs the medical specialty can been seen in the table (A.1). It is possible to notice that the unavailability of the Post-Anesthetist Recovery Room (SRPA, 18 vacancies), The Neurosurgical Critical Care Unit

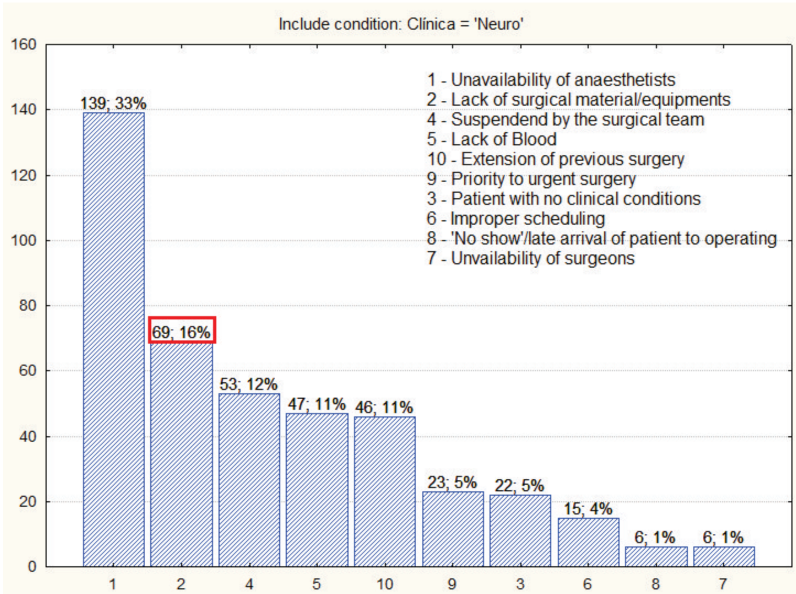

Figure 5.18: Neuro-Surgeries Cancelled by Reason.

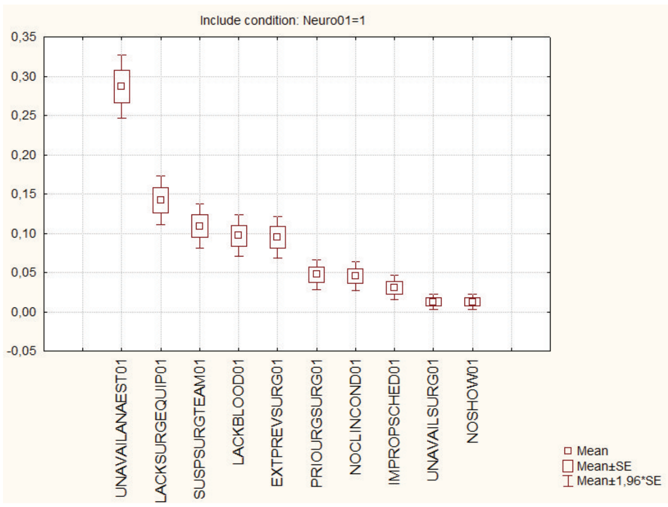

Figure 5.19: Box Plot Neuro-Surgeries Cancelled by Reason.

(USAN, 10 vacancies) and the ICU (40 vacancies) are reasons for surgical cancellations and therefore are limiting factors for the dynamic of the hospital.

If an anesthetist or a surgeon delays to get to the hospital in an average day, it can a´ects the agenda of all the surgeries in that day. Suppose that an anesthetist is not at the hospital at the time the surgery should start. While he does not arrive, the surgeon waits – it means an expensive idle time. Meanwhile, the operating room is ready to use with ar-conditioning running, disposable or sterilized materials, etc. If it is a busy day, the last patient will have his surgery cancelled because there will not have time enough

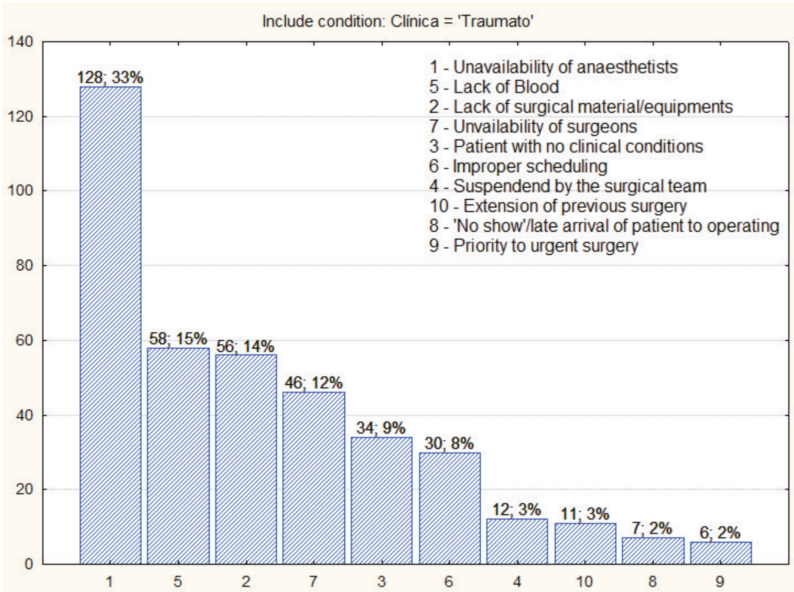

Figure 5.20: Traumatology Surgeries Cancelled by Reason.

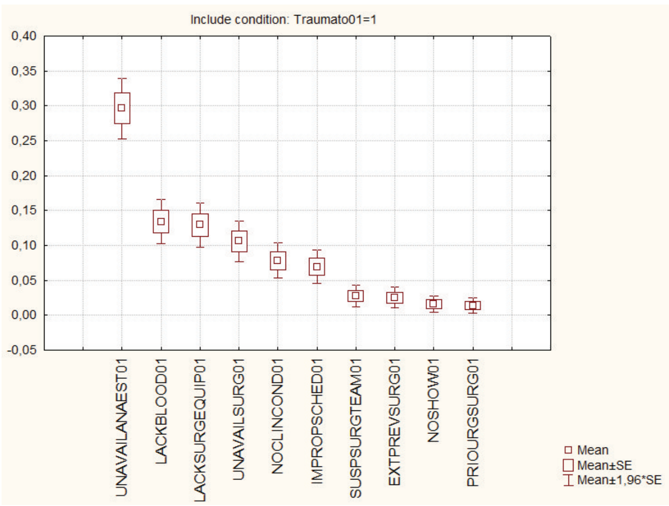

Figure 5.21: Box Plot Traumato-Surgeries Cancelled by Reason.

in the end of the day to perform all surgeries. After a night without sleeping and a day of waiting, anxious about his surgery, and few hours of fasting, the patient will return to his bed because of a personal problem of one doctor in the beginning of the day. The family of the patient is also a´ected and sometimes patients consider situations like this as a “divine sign”, refusing to do the surgery in the future. Of course this is a totally hypothetical situation, but the point is: are the physicians aware about the consequences of their actions for all agents involved in a surgical procedure?

The figure (5.26) shows the di´erence between the λ and μ in the period of 13 months

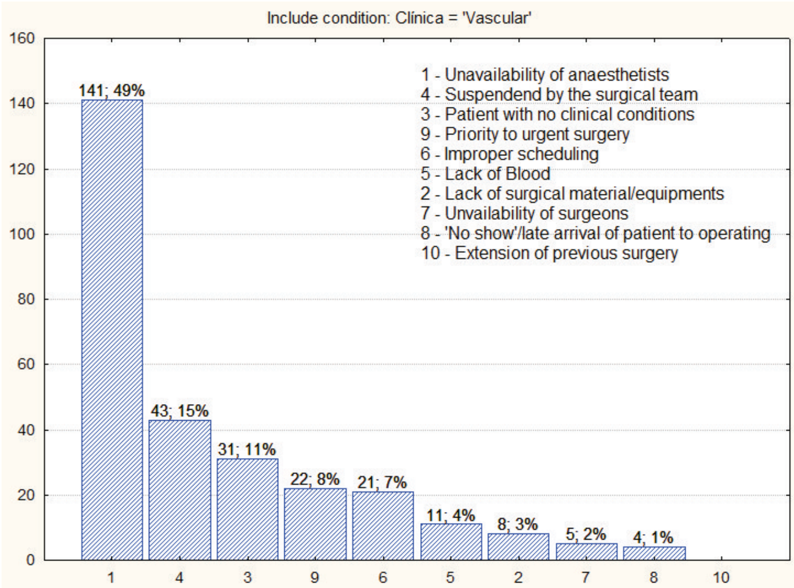

Figure 5.22: Vascular Surgeries Cancelled by Reason.

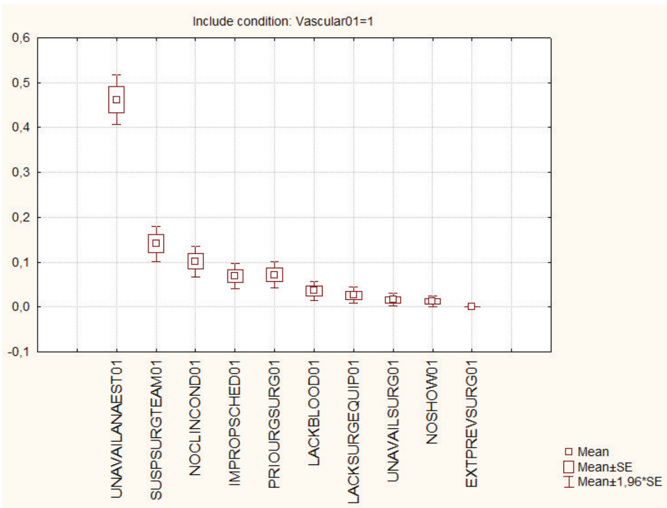

Figure 5.23: Box Plot Vascular Surgeries Cancelled by Reason.

for all surgical specialties in the hospital as an average of the customers per day. The tra¸ c intensity measures how busy the system is and it is defined as the ratio of mean service time to mean interarrival time. If the tra¸ c intensity is greater than one then the queue will grow without bound, which it is the case here. There is a significant gap between the λ and the μ, $\lambda > \mu$, and the relationship $\rho = \frac{\lambda}{\mu}$ is higher than one. If $\rho < 1$, get the following stationary distributions with probability mass function. The behaviour of $\frac{\lambda}{\mu}$ confirms that the hospital cannot meet the demand and the figure (5.27) shows the e´ort to change the situation. There is no softness in the control of the surgical center

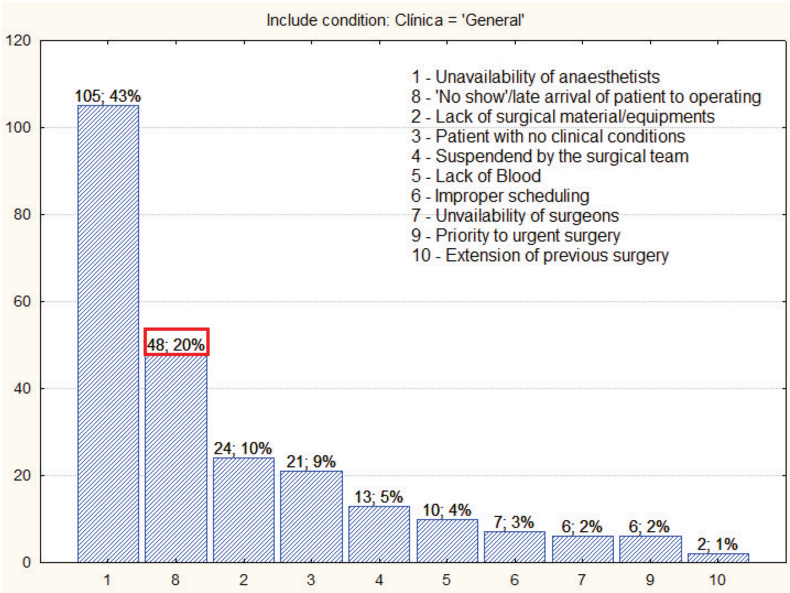

Figure 5.24: General Surgeries Cancelled by Reason.

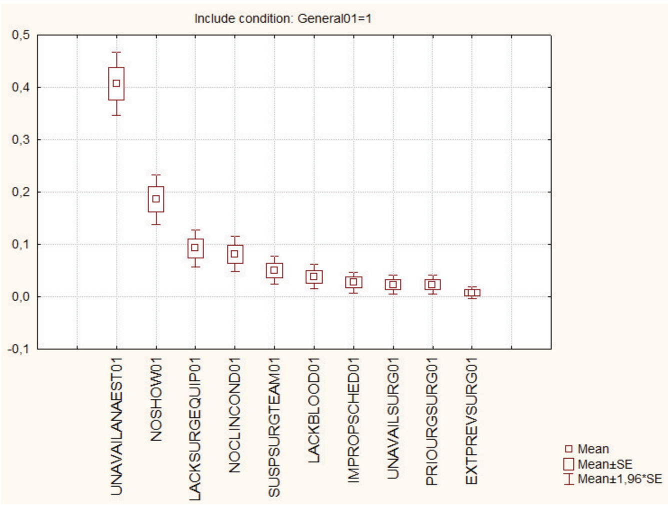

Figure 5.25: Box Plot General Surgeries Cancelled by Reason.

queues. The graph presents an oscillation over time (limity-cicle), a saturation of the system: when the relationship $\frac{\lambda}{\mu}$ is too high, the hospital management does a task force to reduce the gap. It is not sustainable, and after a while the rate goes back to a critical situation. There are peaks and valleys, representing a structural problem.

The figure 5.28 emphasizes this a¸rmation and shows the di´erence between the rate of the arrival rate and the service rate in the surgical specialties of the Hospital da Restaura%ão. The relationship in this graph is the number of patients per day.

When a surgery is cancelled, the health sector queue is growing up. Surgery suspen-

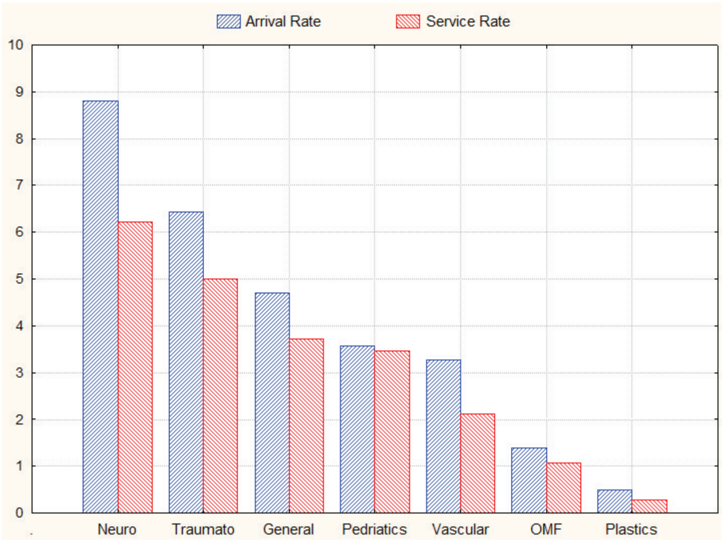

Figure 5.26: Surgical Cancellations of the HR by Specialty.

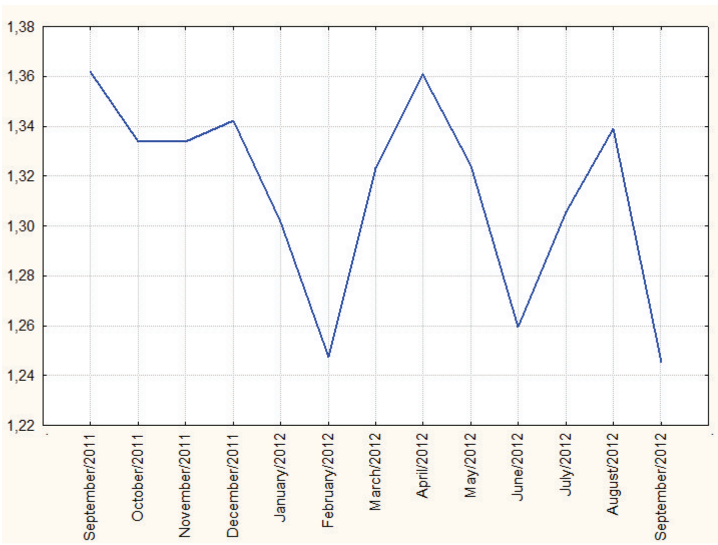

Figure 5.27: Utilization Rate of the System $\left(\frac{\lambda}{\mu}\right)$.

sions reduce the productivity of a hospital, harms the image of the hospital and increases the queue in the hall. Programs are being implemented in Hospital da Restauração around this issue.

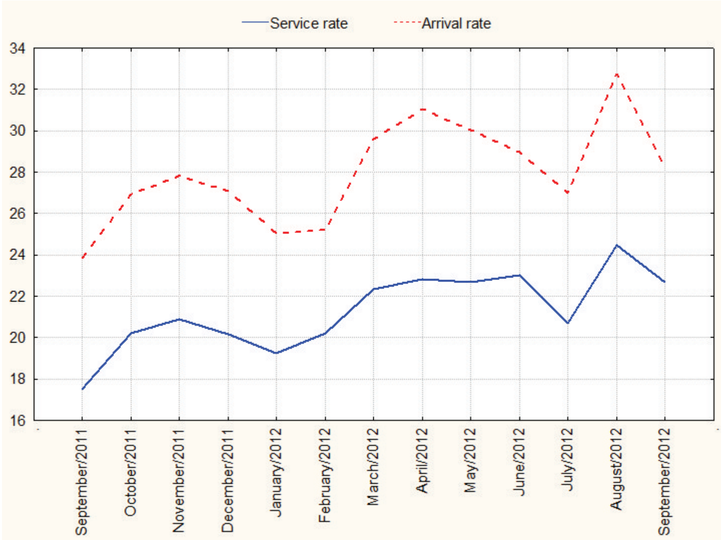

Figure 5.28: Service Rate and Arrival Rate in the HR Surgical Center.

5.3.1 Suggestions to reduce the Surgical Cancellations at the Hospital da Restauração

1. To hire an extra-nurse to perform the pre-exams and to track the patient schedule. It will reduce the numbers of surgeries cancelled because the "patient was fed" (2ff); and the "patients with no clinical condition" (8ff). The patient will be well informed about the surgery and the special care before the surgery.

2. To standardize the data entry. There are simple and e¸ cient tools for it.

3. To indicate the main patient and the patients on the waiting list for the surgery scheduled.

4. To conduct training among the employees involved in the surgical procedures, mainly nurses and physicians. The training must have the goal of explaining the importance of an appropriate and standardized data entry, and to present the possible advantages for the hospital management, and consequently the hospital sta´ .

5. To monitor the cancellation reasons, what will be easier with the database standardized. The constant analysis of the surgeries cancelled will allow better management of the surgery output.

6. To integrate all required information about the patient on the same platform. Integration with other hospitals would be better.

6 AN OPTIMAL CONTROL MODEL

"The purpose of a model is not be realistic. After all, we already possess a model that is completely realistic — the world itself." (Romer, 1996)

Likewise in the maintenance engineering, in the Health System it is necessary to constantly measure the processes and check the people related to them. The Availability of the health system needs to be considered to calculate the economic productivity. The economic system can be producing or in a failure state. The probability of a system be ready to usage depends on the **Reliability** and the **Maintainability** of the system. The availability is a function of reliability and maintainability, and one wants to maximize this function subject to its cost. The total cost can be at least the same of the income of this system. Mathematically, the problem may be placed as follows

$$\underset{R,M}{Max} A = A(R, M)$$

subject to

$$C_R R \,\$\, C_M M \leq I$$

From where A is the availability, R is the reliability, M maintainability and I income. The reliability is the failure rate — or the $\frac{1}{\lambda}$ of a health system — and the maintainability is the time demanded to have a person recovered once he got sick and entered in the health system, the μ. According to Campello de Souza (2007) in an economic argument, the reliability is the capital (K) and the maintainability is the labour force (L). The availability is the income in the productive process.

The rate in which people in the community become sick is the arrival rate of the patients in the health system. The λ is the fraction of the population who is illness. Any time an economically active person become ill, the productivity of the system falls. If a person dies and the community does not have a population growth rate, the productivity of the system will decrease in a given rate. Freitas (2009) considers the morbidity rate an extraction factor of the manpower in the productive system. It is expected a minimum number of patients in a community the same way that it is minimized the number of broken equipments in a factory.

The health system allows the labor force to be recovered **for the productive system**. The labour force **in the health system** is the service attendance rate (μ). The professionals in the health system are responsible to keep the economical system working. They are the recovery system, a maintainability mechanism. To describe the health dynamic, it is not considered the cases when the patient does not enter in the system, like the situations in which the patient dies before attendance by the ambulance or hospital. After a patient gets into the system and receive the service, he/she can get out of this system in four conditions:

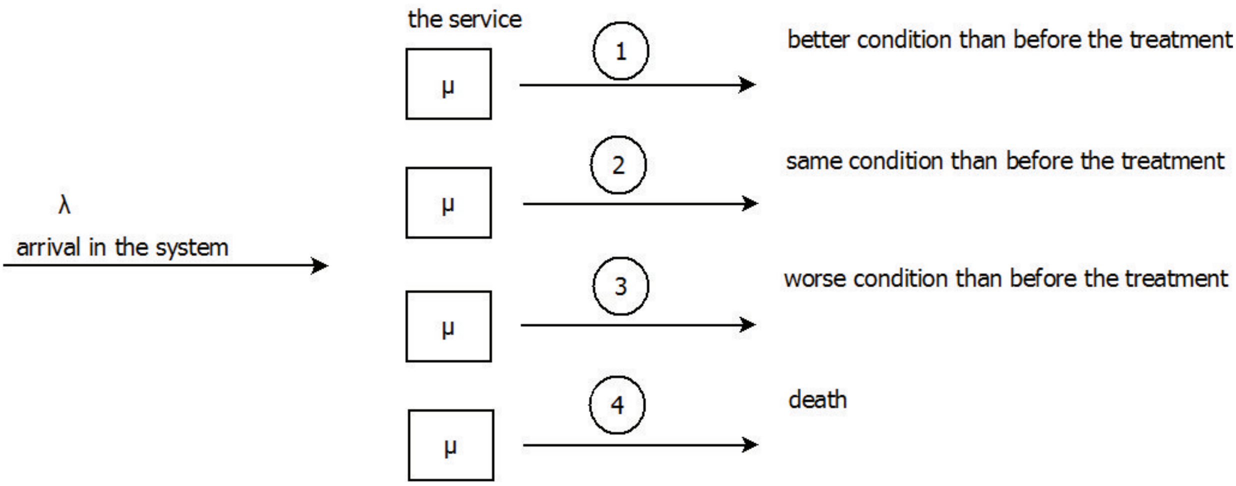

Figure 6.1: Diagram with the possible outputs of a person in the health system.

The concept of this diagram was introduced in Freitas (2009). The output of the health queue model is the availability of the production system. The higher is the availability, higher is the economic growth. The probability of each one of the outputs will depend on the hospital management.

1. **The patient goes out of the health system in better conditions than before the treatment**: It is the case of patients who do transplants. It raises the productivity of the person and consequently in the productive system.

2. **Same condition than before the treatment**: The system totally recovers the patient health. The worker is as productive as before.

3. **Worse condition than before the treatment**: It is the case of severe car/motorcycle accidents, for example, in which some individuals go out of the health service without a leg or with severe brain damage; with less health. The person will be back to the economic system with lower productivity and it is worse for the economy because sometimes the government has to spend in the anticipated retirement of those people.

4. **Death**: The patient will not return to the productive system. The death can be caused by extern variables as an unexpected accident, because the bad habits of the person — *live sedentary, eat much sugar/salt/fatness food or does not go to the doctor for preventive treatments* – or even because of an error in the treatment — *malpractice or delay in the service*

There is also a situation in which a person does not go out of the system. It is when he/she has a chronic disease (SIDA, diabetes, etc) and he/she will depend on the system to keep him/her updated in the medicine treatments, the drugs supply.

The sick people is the raw material for the curative health system but not necessarily for the preventive health system. The **preventive health** aims to educate healthy people to not get sick. The investments in the preventive health can increase the μ of the health system and consequently reduce the queue in this sector. These programs guarantee that a person will not go to the hospital because a dehydration, for example, releasing the health system to treat the important cases. It also increases the λ because identifies diseases before it become more severe. In a long run, better educated population can reduce the health queues.

The health and education sectors can be thought as a set with low and high limits (figure 6.2).

Each point of this set is a person in the society. There is a minimum of health and education a person needs to have to be productive to the economy. Considering the *Quetelet* man, there is a point in which the person can have even more health but he will not have considerable contribution for the economical production in the average. The person in the

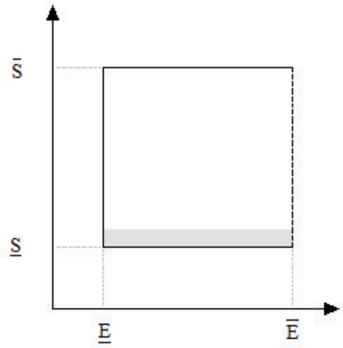

Figure 6.2: Set of Health vs Education in the Economy Productivity.

point $(\overline{S}, \underline{E})$ is a person who works with his (manual) workforce predominantly. The left lower limit $(\underline{S}, \overline{E})$ is the case of a person who has a minimum of health, but he had a lot of investment in education and because of this can contribute for economy with knowledge – Stephen Hawking case. People with genetic or congenital problems, the smokers and the people with the diseases generated by stress and sedentary lifestyle (diabetes and cardiovascular diseases, for example) can be at any point next to the lower limit of health (shaded area of the figure 6.2).

Since there is no limit for education, more education can increase the production of the economy which is the case of the R ffi D sector – in health sector particularly, with the stem cell research, for example. It indicates the health sector has an increasing returns to scale. In the model developed, although, it is assumed constant returns to scale by simplification.

The social background could strongly determine the incidence of a disease. People can have no health because they are poor and do not have money to take care of their own health. And people can be poor because their health is impaired and they will not be able to work to have money. Health is a propulsive tool for the development. An increase in the production raises the economic growth of a country. The lower is the sick people rate or the faster is the return of recovered people to the productive system it raises the productivity of the economy trough workforce and it raises the economic growth trough consumption. The growth economy rate directly depends on the probability of people getting sick. This probability is non-uniformly distributed among people. Poor people are more vulnerable to contract diseases. Because people get sick and die, it is necessary the study of an economic growth model to understand the dynamics of the labor force, the population, in the economic system.

6.1 The Dynamical Systems

Dynamical systems are characterized by states that change with time. They are used to modeling and forecasting. It is important to understand how the sub-systems interact with each other, the basic structure, so the system can be seen as a whole. The model developed here is a deterministic, an autonomous and a linear system.

> *In mathematical terms, the problem of the Control Problem is that of choosing time paths for certain variables, called* ***control variables****, from a given class of time paths, called the* ***control set****. The choice of time paths for the control variables implies via a set of differential equations, called the* ***equations of motion****, time paths for certain variables describing the system, called* ***the state variables*** *and the time paths of the control variables are chosen so as to maximize a given functional depending on the time paths for the control and the state variables, called the* ***objective functional****. (Chiang, 1992)*

The solution of this problem can be found by three methods: Calculus of Variations, Dynamic Programming and Optimal Control Theory.

The brachistochrone problem originated the **calculus of variations** in 1696. The solution of the calculus of variation is dependent on the fist order condition – the Euler–Lagrange Equation – and it is necessary to assure that the objective functional is being maximized or minimized through the second order conditions. However, it cannot be solved directly when the control variables are restricted to a given control set, a weakness overcame by the newer approaches of dynamic programming and the maximum principle (Chiang, 1992).

According to Bellman (1954) the basic idea of the theory of **dynamic programming** is that of viewing an optimal policy as one determining the decision required at each time in terms of the current state of the system. It was created to treat mathematically the multi-stage decision problems. The solution of a dynamic optimization problem would thus take the form of an optimal time path for every choice variable, detailing the best value of the variable today, tomorrow, and so forth, till the end of the planning period (Chiang, 1992). The dynamic programming problem is more general than the classical calculus of variations problem (Intriligator, 2002) but when the dimension of the system is very large for numerical solution of Bellman's equation, it is required vastly computer processing time – *the curse of dimensionality.*

The **optimal control theory**[1] is a modern approach to the dynamic optimization without being constrained to interior solutions, nonetheless it still relies on differentiability. While the calculus of variations has the goal of finding the optimal time path for a **state** variable, the optimal control theory has as its foremost aim the determination of the optimal time path for a **control** variable (Chiang, 1992). Once the optimal path of the control variables $\{u(t)\}$ is found, the solution to the state variables $\{x(t)\}$ are derived. The fundamental elements for the optimal control problem formulation are the **functional objective** to be maximized, the **differential equations** to represent the equilibrium conditions and the **boundary conditions** to detail the initial and final states in the economy.

The functional objective reflects the main objective of the agent. Mathematically represents a efficacy measure of a policy to be implemented. Its argument can be a composed or a vectorial functions. According to Riesz's representation theorem under certain weak conditions, a functional can be represented by an integral. To evaluate the instantaneous satisfaction, it is inserted in the equation an adjustment factor to incorporate the impatience of the population, bringing to the same moment all future evaluations – the social or monetary discount rate.

The control path and state path does not have to be continuous to become admissible. Control path needs to be piecewise continuous and state path needs to be piecewise differentiable (figure 6.3).

The equation

$$\frac{dx}{dt} = f(x, u, t)$$

[1]An economic explanation of the Optimal Control Principle is described in (Dorfman, 1969)

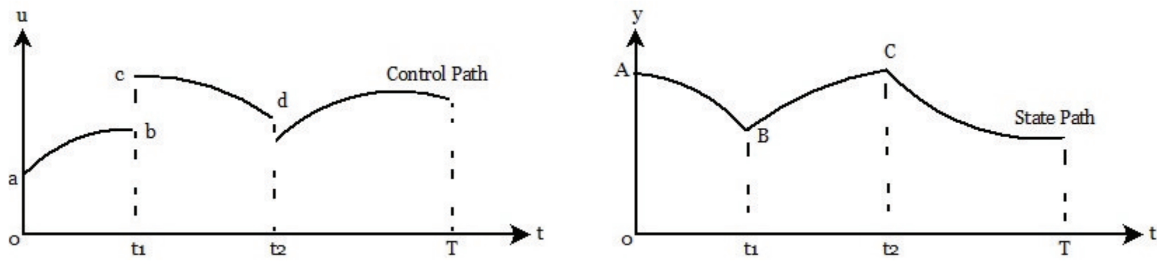

Figure 6.3: Special Features of Optimal Control (Chiang, 1992).

is a restriction of the problem, called the equation of motion – transition equation, or even state equation – and shows how, at any moment of time, the planner's choice of u will drive the state variable x over time[2]. The f satisfies a Lipschitz's condition. In mathematical notation, the problem can be described as

$$\operatorname*{Max}_{u} \int_{t_0}^{t_1} I(x,u,t)\,\mathrm{d}t$$

in where t is the time; t_0 and t_1 are the initial and final instants, respectively.

$$u : R \longrightarrow R^p$$

$$t \to \overrightarrow{u}(t)$$

is the politics – control force or control variable. The direction of the control variable at initial time is completely determined by a choice of $u(t)\mid_{t=0}$.

$$u : R \longrightarrow R^n$$

$$t \to \overrightarrow{x}(t)$$

represents the *status quo* in the t instant – the state variable. And

$$I(x,u,t) = e^{-\delta t} v(x,u,t)$$

[2]When the equation of motion takes the form $\dot{y} = u(t)$ the problem reduces to a calculus variation discussion.

is the value function (v) weighted by impatience. I is Lebesgue integrable.

The first order condition in optimal control theory is the **Pontryagin's Maximum Principle** (1962). The maximum principle involves two first-order equations: in the state variable x and in the costate variable y. There is also a requirement that the Hamiltonian needs to be maximized with respect to the control variable u at every point of time. The Pontryagin's Maximum Principle are the optimally necessary conditions to allow the establishment of the optimal economic policies. The conditions of this model can be described as:

$$\underset{u}{\text{Max}} H(x, u, y, t) \; \forall \, t \;\in\; [0, T]$$

Equation of Motion for x:

$$\dot{x} = \frac{\partial H}{\partial y}$$

Equation Motion for y:

$$\dot{y} = -\frac{\partial H}{\partial x}$$

Transversality Condition:

$$y(T) = 0$$

The both equations of motion are referred to as Hamiltonian System and they are first order di´erential equations. There is no di´erential equation for the control variable.

The hamiltonian can be represented by

$$H(x, u, y, t) = I(x, u, t) \; \$ \; y^T f(x, u, t) \tag{6.1.1}$$

in which y is the costate variable also known as the Pontryagin's multiplier (much like the Lagrange's multiplier in the static optimization) which has a shadow price connotation of a unit of terminal capital stock. The second component of the Hamiltonian represents the rate of change of capital value corresponding to policy u. If a particular policy decision u is favorable to the current profit, then it will normally involve a sacrifice in the future profit (Chiang, 1992).

The hamiltonian is maximized by choosing u. If there is an interior solution for this problem and I is di´erentiable with respect to u, the solution will be obtained from the maximization of $\frac{\partial H}{\partial u} = 0$ at each point of the optimal trajectory. But if there is no interior solution, it is necessary to consider the restrictions in the control variables and apply the Karush-Kuhn-Tucker conditions. After solved the problem, it will have $u^* = u^*(x, y, t)$. During the optimal path the hamiltonian is constant.

It is necessary to replace the value of u in the $2n$ di´erential equations:

$$\frac{\partial x}{\partial t} = \frac{\partial H}{\partial y}$$
$$\frac{\partial y}{\partial t} = -\frac{\partial H}{\partial x}$$

Once solved these equations, the value must replace the optimal value u expressions and the optimal problem is solved.

6.2 Assumptions of the Model

The basic approach adopted in this model is to consider the utilitarian structure, assuming both an exponential growth of the labor force and exponential depreciation of the capital.

In this model, the workforce is the population, it means there is no unemployment and it is not considered the Not Economically Active Population (NEAP). Consumption distribution among the labor force is not modeled – it is used an individual average.

It is assumed that people are indi´erent between save the money for the future generation and spend the money in consumption, as long as they have an interest rate of discount to compensate the action.

A possible limitation of the model is its deterministic characteristic which does not considers possible random aspects in the economic growth. It is also not considered the technological progress in the models.

The utility function u is continuous and strictly concave in $\mathbb{R}^+$. It is homogenous of first degree and it is also a class C_2 in $\mathbb{R}^+$.

6.2.1 Notation

J = intertemporal welfare function

δ = social rate of discount

L = total labor force

u = per capita instantaneous utility function

c = per capita consumption of non-energy goods

t = time

α = per capita consumption of energy goods

β = labor force growth rate

F = production function of the economy

S = the fraction of healthy people

E = the fraction of people who have years of formal study

The subscripts used in the remaining variables have the following meanings:

a. 0 refers to the economy. So,

K_0 = capital for the production of the economy

L_0 = labor allocated to the production of the economy

I_0 = investment for the accumulation and restoration of capital K_0

γ_0 = depreciation rate of capital K_0

b. S is the fraction of healthy people and it refers to the dynamics in the health system and E refers to the education system. So,

F_S = production function for the health system

K_S = capital for the production of the health system

L_S = labor allocated to the production of the health system

I_S = investment for the accumulation and restoration of capital K_S

γ_S = depreciation rate of capital K_S

F_E =production function for the education system

K_E =capital for the production of the education system

L_E =labor allocated to the production of the education system

I_E =investment for the accumulation and restoration of capital K_E

γ_E =depreciation rate of capital K_E

6.3 The Model for the Health System

The model has the objective of maximize an inter-temporal social welfare function subject to the constraints defined by income and investment identities, production technologies, the dynamic of the growth of labor force and education and health rates. It was based in Stamford da Silva ffi Campello de Souza (2008) model for energy. Maximization is achieved by a choice of investments for each sector.

6.3.1 The Income Identitiy

The model analysed characterizes economics in a aggregative way. The sector to be analysed can be explicit in the income identity function.

$$Y = F(K_0, L_0, S) = I_0 \,\$\; I_S \,\$\; L \cdot c \tag{6.3.1}$$

The income identity admits the market in equilibrium. It is a basic identity to the neoclassical growth model representing the products of the economy in the aggregated form.

6.3.2 The Investment Identities

The investment identity presents the instantaneous and absolute variation of K_i which is the depreciation of the capital plus the investment.

$$\frac{dK_0}{dt} = -\gamma_0 K_0 \,\$\; I_0 \tag{6.3.2}$$

$$\frac{dK_S}{dt} = -\gamma_S K_S \$ \; I_S \tag{6.3.3}$$

6.3.3 Production Technologies

If one needs to establish optimal politics to determined sector, the production function can have more explicit arguments. In this case, the health sector: $F(K_0, L_0, S)$. It is assumed that the health system is in equilibrium. It is considered to be concave, twice di´erentiable and homogeneous in some degree for all positive factor inputs (Intriligator, 2002)

$$\frac{\partial F}{\partial K_0}(K_0, L_0, S) > 0; \quad \frac{\partial^2 F}{\partial K_0^2}(K_0, L_0, S) < 0 \tag{6.3.4}$$

$$\frac{\partial F}{\partial L_0}(K_0, L_0, S) > 0; \quad \frac{\partial^2 F}{\partial L_0^2}(K_0, L_0, S) < 0 \tag{6.3.5}$$

The production technology for the health system is expressed by:

$$S = F_S(K_S, L_S) \tag{6.3.6}$$

in where

$$K_S = \frac{1}{\lambda}$$

and $L_S = \mu$. S is defined by the fraction between the number of healthy people and the total labor force and $0 \leq S \leq 1$. K_S is the capital invested in the health system to cure the population. And L_S is the labor force in the health system: nurses, physicians, etc.

6.3.4 Labor Force Evolution Dynamics

The total labor force is the population

$$L = L_0 \$ \; L_S \tag{6.3.7}$$

and its growth is described for the following di´erential equation

$$\frac{dL}{dt} = \beta L \tag{6.3.8}$$

If $\frac{dL}{dt} = 0$ there is a perfect equilibrium between births and deaths. The β is considered here to be positive ($\beta > 0$). If in an hypothetical situation, the recovery system is ine¸ cient and the population growth rate is not positive, the economic productivity will fall down.

6.3.5 The Objective Function

The objective function in the form of an inter-temporal utility is given by:

$$J = \int_0^\infty e^{-\delta t} L \cdot u(c, \beta)\, \mathrm{d}t \tag{6.3.9}$$

u is the inter-temporal utility as a function of the consumption per worker c and the population growth rate β. The utility function u(.) is, so, a nonnegative concave increasing function of per capita consumption of family members. The discount rate, δ, is constant.

It is assumed that the central planner has a utility function that gives utility as function of consumption per worker, c, and population growth rate, β.

6.3.6 State and Control Variables

The state variables are K_0, K_S and L. And the control forces are $I_0 and I_S$. The β is not considered a control force in this case because (1) the focus of the model is on short and medium term; and (2) Brazil does not focus in controlling population growth.

6.3.7 Problem Synthesis

$$\underset{I_0, I_S}{\text{Max}} \int_0^\infty e^{-\delta t} L \cdot u(c, \beta)\, \mathrm{d}t \tag{6.3.10}$$

subject to

$$F(K_0, L_0, S) = I_0 \,\$\; I_S \,\$\; L \cdot c \tag{6.3.11}$$

$$\frac{dK_0}{dt} = -\gamma_0 K_0 \,\$\; I_0 \tag{6.3.12}$$

$$\frac{dK_S}{dt} = -\gamma_S K_S \,\$\; I_S \tag{6.3.13}$$

$$S = F_S(K_S, L_S) \tag{6.3.14}$$

$$\frac{dL}{dt} = \beta L \tag{6.3.15}$$

6.3.8 The Hamiltonian

The Hamiltonian is given by:

$$H = e^{-\delta t}[Lu(c, \beta) \,\$\; q_0(-\gamma_0 K_0 \,\$\; I_0) \,\$\; q_S(-\gamma_S K_S \,\$\; \gamma_S \,\$\; I_S) \,\$\; q_L \beta L] \tag{6.3.16}$$

where $e^{-\delta t}q_0$, $\mathrm{e}^{-\delta t}q_S$ and $e^{-\delta t}q_L$ are the costate variables. It means that in the balance, for the variables with q_0 and q_S, the additional utility is caused by the raise in the capital of a sector. In the case of q_L, the additional utility is caused by the increase of the labor force.

$$c = \frac{1}{L}\left[F(K_0, L_0, S) - I_0 - I_S\right] \tag{6.3.17}$$

and

$$\frac{\partial c}{\partial F} = \frac{1}{L}$$

$$\frac{\partial c}{\partial I_0} = \frac{\partial c}{\partial I_S} = -\frac{1}{L}$$

6.3.9 Preliminary Results

From the application of the Pontryagin Maximum Principle, the optimality conditions can be found:

$$q_i = \frac{\partial u}{\partial c} \tag{6.3.18}$$

for $i = 0, S$. That is, in the optimal path, the marginal value of capital (K_i) must be equal to the marginal utility regarding the consumption per worker. It specifies the value of adding more capital to the system.

$$q_L = -\frac{\partial u}{\partial \beta} \tag{6.3.19}$$

Establishes the value in the optimum path to increase one worker in the economic system, q_L, which is exactly the disutility caused by the population growth. In other words, the shadow price of labor force in the economy must be equal to the negative marginal utility regarding the labor force growth rate.

An important result from the first model is the equality of the shadow-prices.

$$\frac{\dot{q}_0}{q_0} = \frac{\dot{q}_S}{q_S}, \tag{6.3.20}$$

In most optimal economic growth models the rate (growing rate) $\frac{\dot{q}_i}{q_i}$ is constant. Typically it depends upon parameters like the discount rate, the depreciation, and the capital marginal productivity. Call this constant a. Then one will have:

$$q_i(t) = q_i(0)e^{at}.$$

One should keep in mind that q_i is a co-state variable, and so represents a shadow price; an opportunity cost for capital (K_i) accumulation. In the instant we start measuring it, this initial value is noted by $q_i(0)$. On the model at hand

$$a = \delta \ \$ \ \gamma_i - \frac{\partial F}{\partial K_i}.$$

If $a > 0$, this means that as time goes by this shadow price will increase, and the respective constrained capital accumulation will lower the economic growth of the economy as a whole. And this dynamics will get worse and worse.

If $a < 0$, on the contrary, the shadow price will decrease as time passes, and eventually (mathematically, when $t \to \infty$) will reach 0, whatever the initial condition $q_i(0)$. In other words,

$$q_i(t) \to 0, \quad \text{as} \quad t \to \infty.$$

The slack of capital accumulation will gradually disappear. In the long run it will disappear. But the transients are always there.

If $a = 0$, this means that $q_i(t) =$ constant, $\quad \forall\ t$. The important point is to keep the rate negative because the shadow price will decrease until reaches zero ($t \to \infty$).

An important result is the (B.6.13) result which demonstrates that the health sector and the non-health sector are equivalents and depend upon the marginal utility elasticity.

From (6.3.9) one can a˜ rm that,

$$\gamma_0 - \frac{\partial F}{\partial K_0} = \gamma_S - \frac{\partial F}{\partial K_S} \tag{6.3.21}$$

which means the higher the marginal productivity for the health, the better for the economy as a whole.

And from

$$\frac{\partial q_L}{\partial t} = (\delta - \beta) q_L \$ \ q_i \left\{ \frac{\partial u}{\partial c} \left[c - \left(\frac{\partial F}{\partial L} \right) \right] \right\} - u(c, \beta), \qquad i = 0, S. \tag{6.3.22}$$

one can notice the growth of the marginal value of the labor force. *Ceteris paribus*, with everything else constant, the larger the discount rate value, the lower the population growth rate, the larger the marginal value of the good (q_0), the larger the consumption per worker, the larger the capital accumulation for the health sector, the lower the utility per worker and the larger the shadow price of the marginal value of the labor force derivative.

6.4 The Model for Health and Education Sectors

There is a strong interaction between health and education. In terms of the economy, there is a clear tradeo´ between both investments and they are basics for the economic development. From the individual point of view, after investing in health (nutrition) the person 'loses' health to educate himself and then utilizes his education to care better of his health. Here it is developed the same model for health but with the addition of an education variable to measure the tradeo´ between the capital invested in health and education sectors.

6.4.1 The Income Identity

$$F(K_0, L_0, E, S) = I_0 \ \$ \ I_E \ \$ \ I_S \ \$ \ L \cdot c$$

Education and Health influences the whole system and it is analysed in this model to understand their trade-o´.

6.4.2 The Investment Identities

The equation for the investment is the same of the health model (equation 6.3.2). But here it is considered a linear relationship between health and education. Expressed by the equations:

$$\frac{dK_S}{dt} = -\gamma_S K_S \ \$ \ I_S \tag{6.4.1}$$

and

$$\frac{dK_E}{dt} = -\gamma_E K_E \ \$ \ I_E \tag{6.4.2}$$

6.4.3 Production Technologies

With $F(K_0, L_0, S, E)$. It is assumed that the education and the health systems are each one in equilibrium. The production technology for the health system is expressed by the equation (6.3.6). The same considerations of the education model are made:

$$\frac{\partial F}{\partial K_0}(K_0, L_0, S, E) > 0; \quad \frac{\partial^2 F}{\partial K_0^2}(K_0, L_0, S, E) < 0 \tag{6.4.3}$$

$$\frac{\partial F}{\partial L_0}(K_0, L_0, S, E) > 0; \quad \frac{\partial^2 F}{\partial L_0^2}(K_0, L_0, S, E) < 0 \tag{6.4.4}$$

Analogously, the production function for the education system is:

$$E = F_E(K_E, L_E) \tag{6.4.5}$$

An investment in education can reduce the most common and chronic diseases. To have a lower λ it is necessary to invest in the preventive health through education. And all the functions $F_i(K_i, L_i)$ are assumed to be twice di´erentiable.

6.4.4 Labor Force Evolution Dynamics

The total labor force is the population

$$L = L_0 \ \$ \ L_S \ \$ \ L_E \tag{6.4.6}$$

and its growth is described for the same di´erential equation (6.3.8).

6.4.5 The Objective Function

$$J = \int_0^\infty e^{-\delta t} L \cdot u(c, \beta) \, \mathrm{d}t \tag{6.4.7}$$

6.4.6 State and Control Variables

The state variables are K_0, K_S, K_E and L. And the control forces are $I_0, I_S and I_E$.

6.4.7 Problem Synthesis

$$\underset{I_0, I_S, I_E}{\mathrm{Max}} \int_0^\infty e^{-\delta t} L \cdot u(c, \beta) \, \mathrm{d}t \tag{6.4.8}$$

subject to

$$F(K_0, L_0, E, S) = I_0 \,\$\, I_E \,\$\, I_S \,\$\, L \cdot c \tag{6.4.9}$$

$$\frac{dK_0}{dt} = -\gamma_0 K_0 \,\$\, I_0 \tag{6.4.10}$$

$$\frac{dK_S}{dt} = -\gamma_S K_S \,\$\, I_S \tag{6.4.11}$$

$$\frac{dK_E}{dt} = -\gamma_E K_E \,\$\, I_E \tag{6.4.12}$$

$$S = F_S(K_S, L_S) \tag{6.4.13}$$

$$E = F_E(K_E, L_E) \tag{6.4.14}$$

$$\frac{dL}{dt} = \beta L \tag{6.4.15}$$

$$L = L_0 \,\$\, L_S \,\$\, L_E \tag{6.4.16}$$

6.4.8 The Hamiltonian

The Hamiltonian is given by:

$$H = e^{-\delta t}[Lu(c, \beta) \,\$\, q_0(-\gamma_0 K_0 \,\$\, I_0) \,\$\, q_S(-\gamma_S K_S \,\$\, I_S) \,\$\, q_E(-\gamma_E K_E \,\$\, I_E) \,\$\, q_L \beta L] \tag{6.4.17}$$

where $e^{-\delta t}q_0$, $\mathrm{e}^{-\delta t}q_S$, $e^{-\delta t}q_E$ and $e^{-\delta t}q_L$ are the costate variables.

$$c = \frac{1}{L}[F(K_0, L_0, E, S) - I_0 - I_E - I_S] \tag{6.4.18}$$

and

$$\frac{\partial c}{\partial F} = \frac{1}{L}; \qquad \frac{\partial c}{\partial I_0} = \frac{\partial c}{\partial I_S} = \frac{\partial c}{\partial I_E} = -\frac{1}{L}$$

6.4.9 Preliminary Results

The capital gains (K_i) must rise according the interest rate δ plus depreciation rate γ_i minus the marginal productivity of the capital, that reduces the impact of the depreciation in the interest rate.

$$\frac{\dot{q}_0}{q_0} = \frac{\dot{q}_S}{q_S} = \frac{\dot{q}_E}{q_E} = \delta \ \$ \ \gamma_i - \frac{\partial F}{\partial K_i}, \qquad i = 0, S, E. \tag{6.4.19}$$

And then, analysing this equality

$$\gamma_0 - \frac{\partial F}{\partial K_0} = \gamma_S - \frac{\partial F}{\partial K_S} = \gamma_E - \frac{\partial F}{\partial K_E} \tag{6.4.20}$$

$$\frac{\partial F}{\partial K_S} \nearrow \ \Rightarrow \ \left(\gamma_0 - \frac{\partial F}{\partial K_0}\right) \searrow \tag{6.4.21}$$

$$\frac{\partial F}{\partial K_E} \nearrow \ \Rightarrow \ \left(\gamma_0 - \frac{\partial F}{\partial K_0}\right) \searrow \tag{6.4.22}$$

it is possible to notice that the higher the marginal productivities for the health and education sectors are, the better for the economy as a whole. See equation (C.6.4).

An equivalent result as found in the first model is valid here:

$$\frac{\dot{q}_i}{q_i} = -\frac{\sigma(c)}{c}\frac{dc}{dt}, \quad i = 0, S, E \tag{6.4.23}$$

the shadow price for the health sector, education sector and non-health-non-education sector are equivalents and depends upon the marginal utility elasticity.

Another important result is the equation that represents the value of adding labor force in the system:

$$\frac{\partial q_L}{\partial t} = (\delta - \beta) q_L \ \$ \ \left\{ \frac{\partial u}{\partial c} \left[c - \left(\frac{\partial F}{\partial L} \right) \right] \right\} - u(c, \beta) \tag{6.4.24}$$

In the neoclassical growth model, it is possible to a˜ rm that marginal productivity of the labor force is the wage $\left(\frac{\partial F}{\partial L} = \text{wage}\right)$. The neoclassical theory is based on the Say's Law, whereby the supply creates its own demand. The validity of the Say's Law implies that: (I) increasing investments requires a drop in the consumption; (II) the interest rate equalizes the investment and the savings. In the model of health and education, it is supposed that the government is increasing investments. And from this first corollary, one can a˜ rm that the consumption will drop in this model.

Being c the marginal propensity to consume, if c is dropping, *ceteris paribus*, there is a decrease in $\frac{\partial u}{\partial c}$ and, so, there is an increase in the shadow-price of labor force. And if the marginal productivity of $\frac{\partial F}{\partial L}$ is decreasing, *ceteris paribus*, there is a raise in the return of the worker to the production (q_L). In other words, the less e˜ cient employees are being eliminated of the economy, the ones with the wage disproportionately higher than the service provided; and, therefore, the economical e˜ ciency is increasing.

6.5 A Second Model for Health and Education Sectors

The last model did not proportionate enough tools to analyse the tradeo´ between health and education. Muurinen (1982) and Van Doorslaer (1987) a˜ rm that an increase in education lowers the rate of depreciation on the stock of health rather than raising productivity in the gross investment production function. And according to Grossman (1999), the more educated people may be more e˜ cient in making investments that lower the rate of time preference for the present. In other work, Grossman (1976) studied the correlation between schooling and health but the results were not conclusive. There is no explicit and clear relationship between education and health and how one influences the other in the literature. The last model could be adapted to

$$\underset{I_0,I_S,I_E}{\text{Max}} \int_0^{\infty} e^{-\delta t} L \cdot u(c,\beta)\, \mathrm{d}t \tag{6.5.1}$$

subject to

$$F(K_0, L_0, S, E) = I_0 \; \$ \; I_E \; \$ \; I_S \; \$ \; L \cdot c \tag{6.5.2}$$

$$\frac{dK_0}{dt} = -\gamma_0 K_0 \; \$ \; I_0 \tag{6.5.3}$$

$$\frac{dK_S}{dt} = -\gamma_S K_S \; \$ \; \gamma_{ES} K_E \; \$ \; I_S \tag{6.5.4}$$

$$\frac{dK_E}{dt} = -\gamma_E K_E \; \$ \; \gamma_{SE} K_S \; \$ \; I_E \tag{6.5.5}$$

$$S = F_S(K_S, L_S) \tag{6.5.6}$$

$$E = F_E(K_E, L_E) \tag{6.5.7}$$

$$\frac{dL}{dt} = \beta L \tag{6.5.8}$$

$$L = L_0 \,\$\, L_S \,\$\, L_E \tag{6.5.9}$$

It is included two new variables in this model:

γ_{SE} = represents how large an investment in health modifies the capital variation in education

γ_{ES} = represents how large an investment in education modifies the capital variation in health

With a previous analysis one can conclude that the model is stable and it has solution. The system of di´erential equations for education and health would be:

$$\begin{bmatrix} \dot{K}_E \\ \dot{K}_S \end{bmatrix} = \begin{bmatrix} -\gamma_E & \gamma_{SE} \\ \gamma_{ES} & -\gamma_S \end{bmatrix} \begin{bmatrix} K_E \\ K_S \end{bmatrix} \,\$\, \begin{bmatrix} I_E \\ I_S \end{bmatrix}$$

It is assumed that the past health has no influence in the future health. On the other hand, the past education has total influence in the present/future education. Education is markovian. Health depreciates faster than education ($\gamma_S > \gamma_E$). With no infrastructure (hospital, basic sanitation, etc) and tools/materials, there is a minimum of health service.

Physicians need medicines, vaccines, equipments and exams to diagnosis and cure. But even with no infrastructure (schools, books) education can be achieved. Anyway, it is possible to enumerate several examples of this: wars that destroyed schools and the case of the Alexandria's library destruction in 273 AC. The only thing a teacher needs is his knowledge. And it does not need materials to exists. In the end, without education, society does not have physicians. So the depreciation rate of health is higher than the depreciation rate of education. On the other hand, the influence of education in health is lower than the influence of health in education. So $\gamma_{SE} > \gamma_{ES}$. The system is characteristic polynomial is:

$$\begin{vmatrix} s \,\$\, \gamma_S & -\gamma_{ES} \\ -\gamma_{SE} & s \,\$\, \gamma_E \end{vmatrix} = (s \,\$\, \gamma_S)(s \,\$\, \gamma_E) - \gamma_{SE}\gamma_{ES}$$

$$s^2 \,\$\, (\gamma_S \,\$\, \gamma_E)s - \gamma_{SE}\gamma_{ES} = 0$$

$$s = \frac{-(\gamma_S \,\$\, \gamma_E) \pm \sqrt{(\gamma_S \,\$\, \gamma_E)^2 - 4\gamma_{SE}\gamma_{ES}}}{2}$$

and the eigenvalues will be the roots of the equation. Since $\gamma_{SE} > \gamma_{ES} > \gamma_S > \gamma_E$ one concludes that the system has real eigenvalues – it will not oscillate.

6.5.1 The Income Identity

$$F(K_0, L_0, E, S) = I_0 \,\$\, I_E \,\$\, I_S \,\$\, L \cdot c$$

Education and Health influences the whole system and it is considered in this model to analyse their trade-o´.

6.5.2 The Investment Identities

The equation for the investment is the same of the health model (equation 6.3.2). But here it is considered a linear relationship between health and education. Expressed by the equations:

$$\frac{dK_E}{dt} = -\gamma_S K_S \,\$\, \gamma_{ES} K_E \,\$\, I_S \tag{6.5.10}$$

and

$$\frac{dK_E}{dt} = -\gamma_E K_E \,\$\, \gamma_{SE} K_S \,\$\, I_E \tag{6.5.11}$$

The higher is the health capital, higher will be the capital growth rate for education, and vice-versa. The parameters γ_{SE}, $\gamma_{ES} > 0$.

6.5.3 Production Technologies

With $F(K_0, L_0, S, E)$. It is assumed that the education and the health systems are each one in equilibrium. The production technology for the health system is expressed by the equation 6.3.6. The same considerations of the education model are made:

$$\frac{\partial F}{\partial K_0}(K_0, L_0, S, E) > 0; \quad \frac{\partial^2 F}{\partial K_0^2}(K_0, L_0, S, E) < 0 \tag{6.5.12}$$

$$\frac{\partial F}{\partial L_0}(K_0, L_0, S, E) > 0; \quad \frac{\partial^2 F}{\partial L_0^2}(K_0, L_0, S, E) < 0 \tag{6.5.13}$$

Analogously, the production function for the education system is:

$$E = F_E(K_E, L_E) \tag{6.5.14}$$

An investment in education can reduce the most common and chronic diseases. To have a lower λ it is necessary to invest in the preventive health through education. And all the functions $F_i(K_i, L_i)$ are assumed to be twice di´erentiable.

6.5.4 Labor Force Evolution Dynamics

The total labor force is the population

$$L = L_0 \ \$ \ L_S \ \$ \ L_E \tag{6.5.15}$$

and its growth is described for the same di´erential equation 6.3.8.

6.5.5 The Objective Function

$$J = \int_0^\infty e^{-\delta t} L \cdot u(c, \beta) \, \mathrm{d}t \tag{6.5.16}$$

6.5.6 State and Control Variables

The state variables are K_0, K_S, K_E and L. And the control forces are $I_0, I_S and I_E$.

6.5.7 Problem Synthesis

$$\underset{I_0,I_S,I_E}{\text{Max}} \int_0^\infty e^{-\delta t} L \cdot u(c,\beta)\,\mathrm{d}t \tag{6.5.17}$$

subject to

$$F(K_0, L_0, E, S) = I_0 \,\$\; I_E \,\$\; I_S \,\$\; L \cdot c \tag{6.5.18}$$

$$\frac{dK_0}{dt} = -\gamma_0 K_0 \,\$\; I_0 \tag{6.5.19}$$

$$\frac{dK_S}{dt} = -\gamma_S K_S \,\$\; \gamma_{ES} K_E \,\$\; I_S \tag{6.5.20}$$

$$\frac{dK_E}{dt} = -\gamma_E K_E \,\$\; \gamma_{SE} K_S \,\$\; I_E \tag{6.5.21}$$

$$S = F_S(K_S, L_S) \tag{6.5.22}$$

$$E = F_E(K_E, L_E) \tag{6.5.23}$$

$$\frac{dL}{dt} = \beta L \tag{6.5.24}$$

$$L = L_0 \,\$\; L_S \,\$\; L_E \tag{6.5.25}$$

6.5.8 The Hamiltonian

The Hamiltonian is given by:

$$H = e^{-\delta t}[Lu(c,\beta)\$\, q_0(-\gamma_0 K_0 \$\, I_0)\$\, q_S(-\gamma_S K_S \$\, \gamma_{ES} K_E \$\, I_S)\$\, q_E(-\gamma_E K_E \$\, \gamma_{SE} K_S \$\, I_E)\$\, q_L \beta L] \tag{6.5.26}$$

where $e^{-\delta t} q_0$, $\mathrm{e}^{-\delta t} q_S$, $e^{-\delta t} q_E$ and $e^{-\delta t} q_L$ are the costate variables.

$$c = \frac{1}{L}[F(K_0, L_0, E, S) - I_0 - I_E - I_S] \tag{6.5.27}$$

and

$$\frac{\partial c}{\partial F} = \frac{1}{L}; \qquad \frac{\partial c}{\partial I_0} = \frac{\partial c}{\partial I_S} = \frac{\partial c}{\partial I_E} = -\frac{1}{L}$$

6.5.9 Preliminary Results

The result (6.4.19) also arises in this third model and then it is possible to a˜ rm that the higher the marginal productivities for the health and education sectors are, the better for the economy as a whole. But it also arises another important interpretation because of the crossed relationship between education and health (γ_{SE} and γ_{ES}):

$$\gamma_0 - \frac{\partial F}{\partial K_0} = \gamma_S - \gamma_{ES} - \frac{\partial F}{\partial K_S} = \gamma_E - \gamma_{SE} - \frac{\partial F}{\partial K_E} \tag{6.5.28}$$

And

$$\gamma_{ES} \nearrow \Rightarrow \left(\gamma_0 - \frac{\partial F}{\partial K_0}\right) \searrow \tag{6.5.29}$$

$$\gamma_{SE} \nearrow \Rightarrow \left(\gamma_0 - \frac{\partial F}{\partial K_0}\right) \searrow \tag{6.5.30}$$

which means that the parameters γ_{ES} and γ_{SE} have an e´ect in the di´erence between the depreciation of the capital K_0, and its marginal productivity $\frac{\partial F}{\partial K_0}$. So, the more the health and education sectors are intertwined, the better for the economy as a whole. These institutional arrangements (γ_{ij}) creates a synergy among the investments and the economic growth.

6.6 Comments

The models presented here followed the social planner's optic in which he can decide to allocate the fraction of investments in capital or labor in the sector he desires, one of them or both, always looking for maximizing the social utility.

To reduce the health queue length ($Ł_q$) or the waiting time in the queue ($Ł_q(t)$) it is required to increase the μ **and** to reduce the $\frac{1}{\lambda}$. Improving the number of servers trough an enhancement in the number (and quality) of physicians; the expansion in the numbers of establishments; or even improving the e˜ ciency of the service are ways to increase the μ. It is what the government has been done with the UPA installations, unburdening the emergency services in reference hospitals. To increase the investments in the basic sanitation and education reduce the $\frac{1}{\lambda}$ of the community. It highlights the importance of the investments in the PSF (Health Family Program).

The K_S in the health model is the $\frac{1}{\lambda}$ and the L_S is the μ of the system. The higher the investments in the preventive health sector, lower will be the inter-arrival time of patients in the health system. And the higher the number of labor force in the health sector, higher will be the service rate of the health sector.

7 CONCLUSIONS, COMMENTS AND SUGGESTIONS

The study in previous chapters concerning the Brazilian health system, focusing the case of the state of Pernambuco, encompassing several aspects, but mainly queueing network problems, as well as the results of an optimal economic growth model and a case study involving the Hospital da Restauração indicate that some conclusions can be drawn concerning the health system management.

CONCLUSIONS

1. The PSF and basic health units (health centres and polyclinics) have strategic importance in the prevention and health protection. The role of those is to reduce the incidence and prevalence of preventable diseases. A proper functioning of these services, with health professionals, material and medicines, can enhance the sectorial policies planning and unburdening the hospitals and emergencies.

2. The government should invest in an integrated health information system for all public hospitals and UPAs. Implementing new tools is a challenge for a sector with high work-load-dynamic, but the benefits in the long run tends to overcome the e´orts.

3. Quality requires continuous assessment, management and improvement of processes. The hospitals should hire *think tank* professionals to measure, analyse, suggests and implement structural changes to improve the hospital performance indicators.

4. Check-lists can assure the patient conditions are quite enough to perform the surgery, and to guarantee the equipment and material conditions are ready to usage can save some expanses.

5. The control of the scheduled surgeries can reduce the patient exposure, diminish the inpatient time, the risk of hospital infection and can reduce the costs of the treatment.

6. The higher the investments in the preventive health sector, lower will be the inter-arrival time of patients in the health system. And the higher the number of labor force in the health sector, higher will be the service rate of the health sector.

7. The higher the marginal productivities for the health and education sectors, the better for the economy as a whole.

$$\delta \; \$ \; \gamma_0 - \frac{\partial F}{\partial K_0} = \delta \; \$ \; \gamma_S - \frac{\partial F}{\partial K_S} = \delta \; \$ \; \gamma_E - \frac{\partial F}{\partial K_E} \tag{7.0.1}$$

8. The parameters γ_{ES} and γ_{SE} have an e´ect in the di´erence between the depreciation of the capital K_0, and its marginal productivity $\frac{\partial F}{\partial K_0}$. So, the more the health and education sectors are intertwined, the better for the economy as a whole.

$$\gamma_0 - \frac{\partial F}{\partial K_0} = \gamma_S - \gamma_{ES} - \frac{\partial F}{\partial K_S} = \gamma_E - \gamma_{SE} - \frac{\partial F}{\partial K_E} \tag{7.0.2}$$

9. The equation

$$\frac{\dot{q}_L}{q_L} = (\delta - \beta) \; \$ \; \left(c - \frac{\partial F}{\partial L} \right) - \frac{u(c, \beta)}{q_L}$$

establishes the growth of the marginal value of the labor force. *Ceteris paribus*, the higher the consumption per worker, the higher is the marginal productivity of the labor force and the lower the population growth rate, the larger the shadow price of the marginal value of the labor force derivative.

COMMENTS

Waiting lines is like a plague in the Brazilian health system. One cannot wait longer to approach this problem.

Some comments are in order. First, one of the obstacles encountered in this dissertation was the di˜ culty in obtaining the data on the Hospital da Restauração as a whole, including the operation of its surgical center. The mentioned hospital does not have a decision support system department or group, and it has a very heavy load. This poses some problems as far as the organization of information is concerned.

The Pernambuco health system as a whole is being submitted to a growth process with a certain unusual, one may say, high speed, which is in itself a good thing to happen. But on the other hand this creates, naturally, the complications of such a growth process. The Hospital da Restauração itself is investing in new medical equipment and new medical sectors. Before implement politics to reduce the waiting lines in the public health sector, the government must understand how the tradeoff quality vs quantity affects the health professional behavior. Growth must come with quality, not only numbers.

As limitations of the study in this dissertation one can mention the lack of research in the queueing health sector in Brazil and the difficulty to obtain updated information from the health information system for municipalities and states. Moreover, to understand the Brazilian health system dynamic is not an easy task and since the research embraces a wide range of subjects, an extensive research was demanded in other to connect the relevant matters analysed in this dissertation.

SUGGESTIONS FOR FUTURE STUDIES

The subject of health systems management poses a lot of challenges. As suggestions for further studies one may include:

1. To develop and implement a simulation model for the Hospital da Restauração queueing network.
2. To develop and implement a simulation model for the Pernambuco health system as a whole.
3. Elaboration and implementation of staffing requirements models in the Pernambuco health system.
4. To study the possibilities of technological support to improve the health queueing networks functioning.
5. To simulate queues in the health system.

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A Appendix - The Case Study: Surgical Cancellation

See next page.

Table A.1: Reason of Surgical Cancellations in the HR vs Medical Specialty

Reason of surgical cancellations	Missing Values	General	Neuro	NeuroPed	OMF	PedSur	Plastics	Traumato	Vascular	Total
Unavailability of anaesthetists	2	105	139	0	30	0	37	128	141	582
Lack of surgical materials/equipments	0	24	68	1	6	0	3	56	8	166
Patient with no clinical conditions	0	21	22	0	13	5	5	34	31	131
Suspended by the surgical team	0	13	51	2	6	2	2	12	43	131
Lack of Blood	0	10	45	2	2	0	2	58	11	130
Improper scheduling	0	7	15	0	6	5	4	30	21	88
Unavailability of surgeons	0	6	4	2	0	0	6	46	5	69
'No show'/late arrival of patient to operating	1	48	6	0	2	0	0	7	4	68
Priority to urgent surgery	0	6	23	0	5	1	0	6	22	63
Extension of previous surgery	0	2	46	0	1	0	0	11	0	60
Unavailability of Beds in the ICU	0	3	19	5	0	0	0	0	3	30
Lack of Complementary Exams	0	4	10	0	1	0	1	8	4	28
Patient fed	0	1	5	0	0	0	4	13	3	26
Unavailability of surgical team	0	1	10	0	2	0	0	6	1	20
Patient refused the surgery	1	2	2	0	0	2	2	8	1	18
Unavailability of Post-Anesthetist Recovery Room (SRPA)	0	1	0	0	0	0	0	7	2	10
Dispensed by cardiologic advice	0	1	1	0	0	0	0	2	3	7
Patient transferred/discharged	0	0	3	0	1	1	0	0	0	5
Patient died	0	0	2	0	0	0	0	0	1	3
Operating room under the Material and Sterilization Center	0	0	0	0	3	0	0	0	0	3
Lack of vacancies at the Neurosurgical Critical Care Unit (USAN)	0	0	2	0	0	0	0	0	0	2
Missing Data	0	2	0	0	0	0	0	1	1	4
Others	0	3	0	0	0	0	0	0	1	4
Total	4	260	473	12	78	16	66	433	306	1648

B Appendix - Obtaining Analytical Results for the Health Model

B.1 Optimal Control Problem

The problem is given as:

$$\underset{I_0,I_S}{\text{Max}} J = \int_0^{\infty} e^{-\delta t} L \cdot u(c,\beta)\,\mathrm{d}t \tag{B.1.1}$$

subject to

$$F(K_0, L_0, S) = I_0 \,\$\; I_S \,\$\; L \cdot c \tag{B.1.2}$$

$$\frac{dK_0}{dt} = -\gamma_0 K_0 \,\$\; I_0 \tag{B.1.3}$$

$$\frac{dK_S}{dt} = -\gamma_S K_S \,\$\; I_S \tag{B.1.4}$$

$$S = F_S(K_S, L_S) \tag{B.1.5}$$

$$\frac{dL}{dt} = \beta L \tag{B.1.6}$$

$$L = L_0 \,\$\; L_S \tag{B.1.7}$$

B.2 The Hamiltonian

$$H = e^{-\delta t}[L \cdot u(c,\beta) \,\$\; q_0(-\gamma_0 K_0 \,\$\; I_0) \,\$\; q_S(-\gamma_S K_S \,\$\; I_S) \,\$\; q_L \beta L] \tag{B.2.1}$$

where $e^{-\delta t} q_0$, $e^{-\delta t} q_S$ and $e^{-\delta t} q_L$ are the costate variables.

Solving c in expression (B.1.2) one gets:

$$c = \frac{1}{L}\left[F(K_0, L_0, S) - I_0 - I_S\right] \tag{B.2.2}$$

from which it follows that:

$$\frac{\partial c}{\partial F} = \frac{1}{L} \tag{B.2.3}$$

$$\frac{\partial c}{\partial I_0} = \frac{\partial c}{\partial I_S} = -\frac{1}{L} \tag{B.2.4}$$

B.3 State and Control Variables

The state variables are K_0, K_S and L. And the control forces are I_0 and I_S.

B.4 The Maximization of the Hamiltonian

$\frac{\partial H}{\partial I_0} = 0,$

$$\frac{\partial H}{\partial I_0} = e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial I_0} \$ \ q_0\right] = 0 \therefore q_0 = \frac{\partial u}{\partial c} \tag{B.4.1}$$

$\frac{\partial H}{\partial I_S} = 0,$

$$\frac{\partial H}{\partial I_S} = e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial I_S} \$ \ q_S\right] = 0 \therefore q_S = \frac{\partial u}{\partial c} \tag{B.4.2}$$

Thus

$$q_0 = q_S \tag{B.4.3}$$

B.5 The Dynamics of the Costate Variables

$\frac{d(e^{-\delta t}q_0)}{dt} = -\frac{\partial H}{\partial K_0}$

$$e^{-\delta t}\left(\frac{dq_0}{dt} - \delta q_0\right) = -e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial F}\frac{\partial F}{\partial K_0} - \gamma_0 q_0\right] \tag{B.5.1}$$

$$\dot{q}_0 = (\delta \$ \ \gamma_0)q_0 - \left(\frac{\partial u}{\partial c}\frac{\partial F}{\partial K_0}\right) \tag{B.5.2}$$

$\frac{d(e^{-\delta t}q_S)}{dt} = -\frac{\partial H}{\partial K_S}$

$$e^{-\delta t}\left(\frac{dq_S}{dt} - \delta q_S\right) = -e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial F}\frac{\partial F}{\partial S}\frac{\partial S}{\partial K_S} - \gamma_S q_S\right] \tag{B.5.3}$$

$$q_S = (\delta \ \$ \ \ \gamma_S)q_S - \left(\frac{\partial u}{\partial c}\frac{\partial F}{\partial S}\frac{\partial S}{\partial K_S}\right) \tag{B.5.4}$$

$\frac{d(e^{-\delta t}q_L)}{dt} = -\frac{\partial H}{\partial L}$

$$-\delta e^{-\delta t}q_L \ \$ \ \ e^{-\delta t} \cdot \frac{dq_L}{dt} = -\left\{e^{-\delta t}\left[\frac{\partial L}{\partial L}u \ \$ \ \ L\frac{\partial u}{\partial L} \ \$ \ \ q_L\beta\right]\right\} \tag{B.5.5}$$

If,

$$L\frac{\partial u}{\partial L} = L\left(\frac{\partial u}{\partial c}\frac{\partial c}{\partial L} \ \$ \ \ \frac{\partial u}{\partial \beta}\frac{\partial \beta}{\partial L}\right) = L\left[\frac{\partial u}{\partial c}\left(\omega\frac{\partial \frac{1}{L}}{\partial L} \ \$ \ \ \frac{1}{L}\frac{\partial \omega}{\partial L}\right)\right] \tag{B.5.6}$$

$$\omega = F(K_0, L_0, S) - I_0 - I_S \tag{B.5.7}$$

and

$$\frac{\partial \omega}{\partial L} = \frac{\partial F}{\partial L} = \frac{\partial F}{\partial L_0}\frac{\partial L_0}{\partial L} \ \$ \ \ \frac{\partial F}{\partial S}\frac{\partial S}{\partial L_S}\frac{\partial L_S}{\partial L} \tag{B.5.8}$$

So,

$$q_L = \delta q_L - u \ \$ \ \ L\left\{\omega\left[-\frac{1}{L^2} \ \$ \ \ \frac{1}{L}\left(\frac{\partial F}{\partial L_0} \ \$ \ \ \frac{\partial F}{\partial S}\frac{\partial S}{\partial L_S}\right)\right] \ \$ \ \ q_L\beta\right\} \tag{B.5.9}$$

$$q_L = (\delta - \beta)q_L - u(c, \beta) \ \$ \ \ \frac{\partial u}{\partial c}\left[\frac{\omega}{L} - \left(\frac{\partial F}{\partial L_0} \ \$ \ \ \frac{\partial F}{\partial S}\frac{\partial S}{\partial L_S}\right)\right] \tag{B.5.10}$$

$$q_L = (\delta - \beta)q_L - u(c, \beta) \ \$ \ \ q_i\left[c - \left(\frac{\partial F}{\partial L_0} \ \$ \ \ \frac{\partial F}{\partial S}\frac{\partial S}{\partial L_S}\right)\right] \tag{B.5.11}$$

$$q_L = (\delta - \beta)q_L \ \$ \ \ q_i\left[c - \left(\frac{\partial F}{\partial L}\right)\right] - u(c, \beta) \tag{B.5.12}$$

B.6 The Resulting Relations

Replacing (B.4.1) in (B.5.2):

$$q_0 = (\delta \ \$ \ \ \gamma_0)\frac{\partial u}{\partial c} - \left(\frac{\partial u}{\partial c}\frac{\partial F}{\partial K_0}\right) \tag{B.6.1}$$

$$q_0 = \frac{\partial u}{\partial c}\left[(\delta \ \$ \ \ \gamma_0) - \left(\frac{\partial F}{\partial K_0}\right)\right] \tag{B.6.2}$$

$$\frac{q_0}{q_0} = (\delta \ \$ \ \ \gamma_0) - \frac{\partial F}{\partial K_0} \tag{B.6.3}$$

Replacing (B.4.2) in (B.5.4):

$$\dot{q}_S = (\delta \$ \ \gamma_S)\frac{\partial u}{\partial c} - \left(\frac{\partial u}{\partial c}\frac{\partial F}{\partial S}\frac{\partial S}{\partial K_S}\right) \tag{B.6.4}$$

$$\dot{q}_S = \frac{\partial u}{\partial c}\left[(\delta \$ \ \gamma_S - \left(\frac{\partial F}{\partial S}\frac{\partial S}{\partial K_S}\right)\right] \tag{B.6.5}$$

And thus,

$$\frac{\dot{q}_S}{q_S} = \delta \$ \ \gamma_S - \frac{\partial F}{\partial K_S} \tag{B.6.6}$$

From (B.4.3) it follows that

$$\frac{\dot{q}_0}{q_0} = \frac{\dot{q}_S}{q_S}, \tag{B.6.7}$$

and then

$$(\delta \$ \ \gamma_0) - \frac{\partial F}{\partial K_0} = (\delta \$ \ \gamma_S) - \frac{\partial F}{\partial K_S}, \tag{B.6.8}$$

that is

$$\gamma_0 - \frac{\partial F}{\partial K_0} = \gamma_S - \frac{\partial F}{\partial K_S} \tag{B.6.9}$$

Note that from equation (B.4.1), for $i = 0, S$, one has:

$$\dot{q}_i = \frac{d}{dt}\left(\frac{\partial u}{\partial c}\right) = \left[\frac{d}{dc}\left(\frac{\partial u}{\partial c}\right)\right]\frac{dc}{dt} = \frac{\partial^2 u}{\partial c^2}\frac{dc}{dt}$$

$$\frac{dc}{dt} = \frac{\frac{dq_i}{dt}}{\frac{\partial^2 u}{\partial c^2}} = \frac{\left[(\delta \$ \ \gamma_i) - \frac{\partial F}{\partial K_i}\right] q_i}{\frac{\partial^2 u}{\partial c^2}} = \frac{\left[(\delta \$ \ \gamma_i) - \frac{\partial F}{\partial K_i}\right]\frac{\partial u}{\partial c}}{\frac{\partial^2 u}{\partial c^2}}$$

Now let

$$\sigma(c) = -c\,\frac{\frac{\partial^2 u}{\partial c^2}}{\frac{\partial u}{\partial c}} \tag{B.6.10}$$

which is called the marginal utility elasticity, a measure of the utility function curvature. Thus

$$\frac{dc}{dt} = -\frac{c}{\sigma(c)}\left[(\delta \$ \ \gamma_i) - \frac{\partial F}{\partial K_i}\right] \tag{B.6.11}$$

$$-\frac{\sigma(c)}{c}\frac{dc}{dt} = \left[(\delta \$ \ \gamma_i) - \frac{\partial F}{\partial K_i}\right] \tag{B.6.12}$$

$$-\frac{\sigma(c)}{c}\frac{dc}{dt} = \frac{q_i}{q_i} \tag{B.6.13}$$

C Appendix - Obtaining Analytical Results for the Health and Education Model

C.1 Optimal Control Problem

The problem is given as:

$$\underset{I_0,I_S,I_E}{\text{Max}}\, J = \int_0^\infty e^{-\delta t} L \cdot u(c, \beta)\,\mathrm{d}t \tag{C.1.1}$$

subject to

$$F(K_0, L_0, E, S) = I_0 \;\$\; I_E \;\$\; I_S \;\$\; L \cdot c \tag{C.1.2}$$

$$\frac{dK_0}{dt} = -\gamma_0 K_0 \;\$\; I_0 \tag{C.1.3}$$

$$\frac{dK_S}{dt} = -\gamma_S K_S \;\$\; I_S \tag{C.1.4}$$

$$\frac{dK_E}{dt} = -\gamma_E K_E \;\$\; I_E \tag{C.1.5}$$

$$S = F_S(K_S, L_S) \tag{C.1.6}$$

$$E = F_E(K_E, L_E) \tag{C.1.7}$$

$$\frac{dL}{dt} = \beta L \tag{C.1.8}$$

$$L = L_0 \;\$\; L_S \;\$\; L_E \tag{C.1.9}$$

C.2 State and Control Variables

The state variables are K_0, K_S, K_E and L. And the control forces are I_0, I_S and I_E.

C.3 The Hamiltonian

$$H = e^{-\delta t}[L \cdot u(c, \beta)\$ \; q_0(-\gamma_0 K_0 \$ \; I_0)\$ \; q_S(-\gamma_S K_S \$ \; I_S)\$ \; q_E(-\gamma_E K_E \$ \; I_E)\$ \; q_L \beta L] \quad \text{(C.3.1)}$$

where $e^{-\delta t}q_0$, $e^{-\delta t}q_S$, $e^{-\delta t}q_E$ and $e^{-\delta t}q_L$ are the costate variables.

Solving c in expression (C.1.2) one gets:

$$c = \frac{1}{L}\left[F(K_0, L_0, E, S) - I_0 - I_E - I_S\right] \quad \text{(C.3.2)}$$

from which it follows that:

$$\frac{\partial c}{\partial F} = \frac{1}{L} \quad \text{(C.3.3)}$$

$$\frac{\partial c}{\partial I_0} = \frac{\partial c}{\partial I_S} = \frac{\partial c}{\partial I_E} = -\frac{1}{L} \quad \text{(C.3.4)}$$

C.4 The Maximization of the Hamiltonian

$\frac{\partial H}{\partial I_0} = 0,$

$$\frac{\partial H}{\partial I_0} = e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial I_0} \; \$ \; q_0\right] = 0 \therefore q_0 = \frac{\partial u}{\partial c} \quad \text{(C.4.1)}$$

$\frac{\partial H}{\partial I_S} = 0,$

$$\frac{\partial H}{\partial I_S} = e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial I_S} \; \$ \; q_S\right] = 0 \therefore q_S = \frac{\partial u}{\partial c} \quad \text{(C.4.2)}$$

$\frac{\partial H}{\partial I_E} = 0,$

$$\frac{\partial H}{\partial I_E} = e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial I_E} \; \$ \; q_E\right] = 0 \therefore q_E = \frac{\partial u}{\partial c} \quad \text{(C.4.3)}$$

Thus

$$q_0 = q_S = q_E \quad \text{(C.4.4)}$$

C.5 The Dynamics of the Costate Variables

$\frac{d(e^{-\delta t}q_0)}{dt} = -\frac{\partial H}{\partial K_0}$

$$e^{-\delta t}\left(\frac{dq_0}{dt} - \delta q_0\right) = -e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial F}\frac{\partial F}{\partial K_0} - \gamma_0 q_0\right] \tag{C.5.1}$$

$$\dot{q}_0 = (\delta \$ \ \gamma_0)q_0 - \frac{\partial u}{\partial c}\frac{\partial F}{\partial K_0} \tag{C.5.2}$$

$\frac{d(e^{-\delta t}q_S)}{dt} = -\frac{\partial H}{\partial K_S}$

$$e^{-\delta t}\left(\frac{dq_S}{dt} - \delta q_S\right) = -e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial F}\frac{\partial F}{\partial S}\frac{\partial S}{\partial K_S} - \gamma_S q_S\right] \tag{C.5.3}$$

$$\dot{q}_S = (\delta \$ \ \gamma_S)q_S - \frac{\partial u}{\partial c}\frac{\partial F}{\partial S}\frac{\partial S}{\partial K_S} \tag{C.5.4}$$

$\frac{d(e^{-\delta t}q_E)}{dt} = -\frac{\partial H}{\partial K_E}$

$$e^{-\delta t}\left(\frac{dq_E}{dt} - \delta q_E\right) = -e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial F}\frac{\partial F}{\partial E}\frac{\partial E}{\partial K_E} - \gamma_E q_E\right] \tag{C.5.5}$$

$$\dot{q}_E = (\delta \$ \ \gamma_E)\, q_E - \frac{\partial u}{\partial c}\frac{\partial F}{\partial E}\frac{\partial E}{\partial K_E} \tag{C.5.6}$$

$\frac{d(e^{-\delta t}q_L)}{dt} = -\frac{\partial H}{\partial L}$

$$-\delta e^{-\delta t}q_L \$ \ e^{-\delta t}\cdot\frac{dq_L}{dt} = -e^{-\delta t}\left[\frac{\partial L}{\partial L}u \$ \ L\frac{\partial u}{\partial L} \$ \ q_L\beta\right] \tag{C.5.7}$$

If,

$$L\frac{\partial u}{\partial L} = L\left(\frac{\partial u}{\partial c}\frac{\partial c}{\partial L} \$ \ \frac{\partial u}{\partial \beta}\frac{\partial \beta}{\partial L}\right) = L\left[\frac{\partial u}{\partial c}\left(\omega\frac{\partial \frac{1}{L}}{\partial L} \$ \ \frac{1}{L}\frac{\partial \omega}{\partial L}\right)\right] \tag{C.5.8}$$

$$\omega = F(K_0, L_0, E, S) - I_0 - I_S - I_E \tag{C.5.9}$$

and

$$\frac{\partial \omega}{\partial L} = \frac{\partial F}{\partial L} = \frac{\partial F}{\partial L_0}\frac{\partial L_0}{\partial L} \$ \ \frac{\partial F}{\partial S}\frac{\partial S}{\partial L_S}\frac{\partial L_S}{\partial L} \$ \ \frac{\partial F}{\partial E}\frac{\partial E}{\partial L_E}\frac{\partial L_E}{\partial L} \tag{C.5.10}$$

So,

$$\dot{q}_L = \delta q_L - u \,\$\; L \left\{ \omega \left[-\frac{1}{L^2} \,\$\; \frac{1}{L} \left(\frac{\partial F}{\partial L_0} \,\$\; \frac{\partial F}{\partial S}\frac{\partial S}{\partial L_S} \,\$\; \frac{\partial F}{\partial E}\frac{\partial E}{\partial L_E} \right) \frac{\partial u}{\partial c} \right] \,\$\; q_L \beta \right\} \tag{C.5.11}$$

$$\dot{q}_L = (\delta - \beta) q_L - u(c, \beta) \,\$\; \frac{\partial u}{\partial c} \left[\frac{\omega}{L} - \left(\frac{\partial F}{\partial L_0} \,\$\; \frac{\partial F}{\partial S}\frac{\partial S}{\partial L_S} \,\$\; \frac{\partial F}{\partial E}\frac{\partial E}{\partial L_E} \right) \right] \tag{C.5.12}$$

$$\dot{q}_L = (\delta - \beta) q_L - u(c, \beta) \,\$\; q_i \left[c - \left(\frac{\partial F}{\partial L_0} \,\$\; \frac{\partial F}{\partial S}\frac{\partial S}{\partial L_S} \,\$\; \frac{\partial F}{\partial E}\frac{\partial E}{\partial L_E} \right) \right] \tag{C.5.13}$$

C.6 The Resulting Relations

Replacing (C.4.1) in (C.5.2):

$$\dot{q}_0 = (\delta \,\$\; \gamma_0) \frac{\partial u}{\partial c} - \left(\frac{\partial u}{\partial c}\frac{\partial F}{\partial K_0} \right) \tag{C.6.1}$$

$$\dot{q}_0 = \frac{\partial u}{\partial c} \left[(\delta \,\$\; \gamma_0) - \left(\frac{\partial F}{\partial K_0} \right) \right] \tag{C.6.2}$$

$$\frac{\dot{q}_0}{q_0} = (\delta \,\$\; \gamma_0) - \left(\frac{\partial F}{\partial K_0} \right) \tag{C.6.3}$$

$$\frac{\dot{q}_0}{q_0} = \delta \,\$\; \gamma_0 - \frac{\partial F}{\partial K_0} \tag{C.6.4}$$

Replacing (C.4.2) in (C.5.4):

$$\dot{q}_S = (\delta \,\$\; \gamma_S) \frac{\partial u}{\partial c} - \left(\frac{\partial u}{\partial c}\frac{\partial F}{\partial S}\frac{\partial S}{\partial K_S} \right) \tag{C.6.5}$$

$$\dot{q}_S = \frac{\partial u}{\partial c} \left[(\delta \,\$\; \gamma_S - \left(\frac{\partial F}{\partial S}\frac{\partial S}{\partial K_S} \right) \right] \tag{C.6.6}$$

$$\frac{\dot{q}_S}{q_S} = \delta \,\$\; \gamma_S - \left(\frac{\partial F}{\partial S}\frac{\partial S}{\partial K_S} \right) \tag{C.6.7}$$

$$\frac{\dot{q}_S}{q_S} = \delta \,\$\; \gamma_S - \frac{\partial F}{\partial K_S} \tag{C.6.8}$$

Replacing (C.4.3) in (C.5.6):

$$\dot{q}_E = (\delta \,\$\; \gamma_E) \frac{\partial u}{\partial c} - \left(\frac{\partial u}{\partial c}\frac{\partial F}{\partial E}\frac{\partial E}{\partial K_E} \right) \tag{C.6.9}$$

$$\dot{q}_E = \frac{\partial u}{\partial c}\left[(\delta \,\$\; \gamma_E) - \left(\frac{\partial F}{\partial E}\frac{\partial E}{\partial K_E}\right)\right] \tag{C.6.10}$$

$$\frac{\dot{q}_E}{q_E} = (\delta \,\$\; \gamma_E) - \left(\frac{\partial F}{\partial E}\frac{\partial E}{\partial K_E}\right) \tag{C.6.11}$$

$$\frac{\dot{q}_E}{q_E} = \delta \,\$\; \gamma_E - \frac{\partial F}{\partial K_E} \tag{C.6.12}$$

From (C.4.4) one gets:

$$\frac{\dot{q}_0}{q_0} = \frac{\dot{q}_S}{q_S} = \frac{\dot{q}_E}{q_E}, \tag{C.6.13}$$

and thus

$$\delta \,\$\; \gamma_0 - \frac{\partial F}{\partial K_0} = \delta \,\$\; \gamma_S - \frac{\partial F}{\partial K_S} = \delta \,\$\; \gamma_E - \frac{\partial F}{\partial K_E} \tag{C.6.14}$$

or

$$\gamma_0 - \frac{\partial F}{\partial K_0} = \gamma_S - \frac{\partial F}{\partial K_S} = \gamma_E - \frac{\partial F}{\partial K_E} \tag{C.6.15}$$

An equivalent result as in (B.6.13) is valid here:

$$-\frac{\sigma(c)}{c}\frac{dc}{dt} = \delta \,\$\; \gamma_0 - \frac{\partial F}{\partial K_0} \tag{C.6.16}$$

$$-\frac{\sigma(c)}{c}\frac{dc}{dt} = \frac{\dot{q}_0}{q_0} \tag{C.6.17}$$

$$-\frac{\sigma(c)}{c}\frac{dc}{dt} = \delta \,\$\; \gamma_i - \frac{\partial F}{\partial K_i}, \quad i = S, E \tag{C.6.18}$$

$$-\frac{\sigma(c)}{c}\frac{dc}{dt} = \frac{\dot{q}_i}{q_i}, \quad i = S, E \tag{C.6.19}$$

From (C.5.13):

$$\frac{\dot{q}_L}{q_L} = (\delta - \beta)\,\$\; \left\{\left[c - \left(\frac{\partial F}{\partial L_0}\,\$\;\frac{\partial F}{\partial L_S}\,\$\;\frac{\partial F}{\partial L_E}\right)\right]\right\} - \frac{u(c,\beta)}{q_L}, \tag{C.6.20}$$

D Appendix - Obtaining Analytical Results for the Second Model for the Health and Education Sectors

D.1 Optimal Control Problem

The problem is given as:

$$\underset{I_0,I_S,I_E}{\text{Max}}\ J = \int_0^{\infty} e^{-\delta t} L \cdot u(c,\beta)\,\mathrm{d}t \tag{D.1.1}$$

subject to

$$F(K_0, L_0, E, S) = I_0 \,\$\; I_E \,\$\; I_S \,\$\; L \cdot c \tag{D.1.2}$$

$$\frac{dK_0}{dt} = -\gamma_0 K_0 \,\$\; I_0 \tag{D.1.3}$$

$$\frac{dK_S}{dt} = -\gamma_S K_S \,\$\; \gamma_{ES} K_E \,\$\; I_S \tag{D.1.4}$$

$$\frac{dK_E}{dt} = -\gamma_E K_E \,\$\; \gamma_{SE} K_S \,\$\; I_E \tag{D.1.5}$$

$$S = F_S(K_S, L_S) \tag{D.1.6}$$

$$E = F_E(K_E, L_E) \tag{D.1.7}$$

$$\frac{dL}{dt} = \beta L \tag{D.1.8}$$

$$L = L_0 \,\$\; L_S \,\$\; L_E \tag{D.1.9}$$

D.2 State and Control Variables

The state variables are K_0, K_S, K_E and L. And the control forces are I_0, I_S and I_E.

D.3 The Hamiltonian

$$H = e^{-\delta t}[L \cdot u(c,\beta)\$ \; q_0(-\gamma_0 K_0\$ \; I_0)\$ \; q_S(-\gamma_S K_S\$ \; \gamma_{ES} K_E\$ \; I_S)\$ \; q_E(-\gamma_E K_E\$ \; \gamma_{SE} K_S\$ \; I_E)\$ \; q_L \beta L] \tag{D.3.1}$$

where $e^{-\delta t}q_0$, $e^{-\delta t}q_S$, $e^{-\delta t}q_E$ and $e^{-\delta t}q_L$ are the costate variables.

Solving c in expression (D.1.2) one gets:

$$c = \frac{1}{L}\left[F(K_0, L_0, E, S) - I_0 - I_E - I_S\right] \tag{D.3.2}$$

from which it follows that:

$$\frac{\partial c}{\partial F} = \frac{1}{L} \tag{D.3.3}$$

$$\frac{\partial c}{\partial I_0} = \frac{\partial c}{\partial I_S} = \frac{\partial c}{\partial I_E} = -\frac{1}{L} \tag{D.3.4}$$

D.4 The Maximization of the Hamiltonian

$\frac{\partial H}{\partial I_0} = 0$

$$\frac{\partial H}{\partial I_0} = e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial I_0}\$ \;\; q_0\right] = 0 \therefore q_0 = \frac{\partial u}{\partial c} \tag{D.4.1}$$

$\frac{\partial H}{\partial I_S} = 0$

$$\frac{\partial H}{\partial I_S} = e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial I_S}\$ \;\; q_S\right] = 0 \therefore q_S = \frac{\partial u}{\partial c} \tag{D.4.2}$$

$\frac{\partial H}{\partial I_E} = 0$

$$\frac{\partial H}{\partial I_E} = e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial I_E} \$ \; q_E\right] = 0 \therefore q_E = \frac{\partial u}{\partial c} \tag{D.4.3}$$

Thus

$$q_0 = q_S = q_E \tag{D.4.4}$$

D.5 The Dynamics of the Costate Variables

$\frac{d(e^{-\delta t}q_0)}{dt} = -\frac{\partial H}{\partial K_0}$

$$e^{-\delta t}\left(\frac{dq_0}{dt} - \delta q_0\right) = -e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial F}\frac{\partial F}{\partial K_0} - \gamma_0 q_0\right] \tag{D.5.1}$$

$$\dot{q}_0 = (\delta \$ \; \gamma_0)q_0 - \left(\frac{\partial u}{\partial c}\frac{\partial F}{\partial K_0}\right) \tag{D.5.2}$$

$\frac{d(e^{-\delta t}q_S)}{dt} = -\frac{\partial H}{\partial K_S}$

$$e^{-\delta t}\left(\frac{dq_S}{dt} - \delta q_S\right) = -e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial F}\frac{\partial F}{\partial S}\frac{\partial S}{\partial K_S} - \gamma_S q_S \$ \; \gamma_{SE}q_E\right] \tag{D.5.3}$$

$$\dot{q}_S = (\delta \$ \; \gamma_S)q_S - \left(\frac{\partial u}{\partial c}\frac{\partial F}{\partial S}\frac{\partial S}{\partial K_S} - \gamma_{SE}q_E\right) \tag{D.5.4}$$

$\frac{d(e^{-\delta t}q_E)}{dt} = -\frac{\partial H}{\partial K_E}$

$$e^{-\delta t}\left(\frac{dq_E}{dt} - \delta q_E\right) = -e^{-\delta t}\left[L\frac{\partial u}{\partial c}\frac{\partial c}{\partial F}\frac{\partial F}{\partial E}\frac{\partial E}{\partial K_E} - \gamma_E q_E \$ \; \gamma_{ES}q_S\right] \tag{D.5.5}$$

$$\dot{q}_E = (\delta \$ \; \gamma_E)\, q_E - \left(\frac{\partial u}{\partial c}\frac{\partial F}{\partial E}\frac{\partial E}{\partial K_E} - \gamma_{ES}q_S\right) \tag{D.5.6}$$

$\frac{d(e^{-\delta t}q_L)}{dt} = -\frac{\partial H}{\partial L}$

$$-\delta e^{-\delta t}q_L \$ \; e^{-\delta t}\cdot\frac{dq_L}{dt} = -e^{-\delta t}\left[\frac{\partial L}{\partial L}u \$ \; L\frac{\partial u}{\partial L} \$ \; q_L\beta\right] \tag{D.5.7}$$

If,

$$L\frac{\partial u}{\partial L} = L\left(\frac{\partial u}{\partial c}\frac{\partial c}{\partial L} \$ \; \frac{\partial u}{\partial \beta}\frac{\partial \beta}{\partial L}\right) = L\left[\frac{\partial u}{\partial c}\left(\omega\frac{\partial \frac{1}{L}}{\partial L} \$ \; \frac{1}{L}\frac{\partial \omega}{\partial L}\right)\right] \tag{D.5.8}$$

$$\omega = F(K_0, L_0, E, S) - I_0 - I_S - I_E \tag{D.5.9}$$

and

$$\frac{\partial \omega}{\partial L} = \frac{\partial F}{\partial L} = \frac{\partial F}{\partial L_0}\frac{\partial L_0}{\partial L} \$ \frac{\partial F}{\partial S}\frac{\partial S}{\partial L_S}\frac{\partial L_S}{\partial L} \$ \frac{\partial F}{\partial E}\frac{\partial E}{\partial L_E}\frac{\partial L_E}{\partial L} \tag{D.5.10}$$

So,

$$\dot{q}_L = \delta q_L - u \$ \ L\left\{\omega\left[-\frac{1}{L^2} \$ \ \frac{1}{L}\left(\frac{\partial F}{\partial L_0} \$ \ \frac{\partial F}{\partial S}\frac{\partial S}{\partial L_S} \$ \ \frac{\partial F}{\partial E}\frac{\partial E}{\partial L_E}\right)\frac{\partial u}{\partial c}\right] \$ \ q_L \beta\right\} \tag{D.5.11}$$

$$\dot{q}_L = (\delta - \beta)q_L - u(c, \beta) \$ \ \frac{\partial u}{\partial c}\left[\frac{\omega}{L} - \left(\frac{\partial F}{\partial L_0} \$ \ \frac{\partial F}{\partial S}\frac{\partial S}{\partial L_S} \$ \ \frac{\partial F}{\partial E}\frac{\partial E}{\partial L_E}\right)\right] \tag{D.5.12}$$

$$\dot{q}_L = (\delta - \beta)q_L - u(c, \beta) \$ \ q_i\left[c - \left(\frac{\partial F}{\partial L_0} \$ \ \frac{\partial F}{\partial S}\frac{\partial S}{\partial L_S} \$ \ \frac{\partial F}{\partial E}\frac{\partial E}{\partial L_E}\right)\right] \tag{D.5.13}$$

D.6 The Resulting Relations

Replacing (D.4.1) in (D.5.2):

$$\dot{q}_0 = (\delta \$ \ \gamma_0)\frac{\partial u}{\partial c} - \left(\frac{\partial u}{\partial c}\frac{\partial F}{\partial K_0}\right) \tag{D.6.1}$$

$$\dot{q}_0 = \frac{\partial u}{\partial c}\left[(\delta \$ \ \gamma_0) - \left(\frac{\partial F}{\partial K_0}\right)\right] \tag{D.6.2}$$

Replacing (D.4.2) in (D.5.4):

$$\dot{q}_S = (\delta \$ \ \gamma_S - \gamma_{ES})\frac{\partial u}{\partial c} - \left(\frac{\partial u}{\partial c}\frac{\partial F}{\partial S}\frac{\partial S}{\partial K_S}\right) \tag{D.6.3}$$

$$\dot{q}_S = \frac{\partial u}{\partial c}\left[(\delta \$ \ \gamma_S - \gamma_{ES}) - \left(\frac{\partial F}{\partial S}\frac{\partial S}{\partial K_S}\right)\right] \tag{D.6.4}$$

$$\frac{\dot{q}_S}{q_S} = (\delta \$ \ \gamma_S - \gamma_{ES}) - \left(\frac{\partial F}{\partial S}\frac{\partial S}{\partial K_S}\right) \tag{D.6.5}$$

$$\frac{\partial F}{\partial K_S} = \delta \$ \ \gamma_S - \frac{\gamma_{SE} q_E}{q_S} \tag{D.6.6}$$

Replacing (D.4.3) in (D.5.6):

$$\dot{q}_E = (\delta \,\$\, \gamma_E - \gamma_{SE}) \frac{\partial u}{\partial c} - \left(\frac{\partial u}{\partial c} \frac{\partial F}{\partial E} \frac{\partial E}{\partial K_E} \right) \tag{D.6.7}$$

$$\dot{q}_E = \frac{\partial u}{\partial c} (\delta \,\$\, \gamma_E - \gamma_{SE}) - \left(\frac{\partial F}{\partial E} \frac{\partial E}{\partial K_E} \right) \tag{D.6.8}$$

$$\frac{\dot{q}_E}{q_E} = (\delta \,\$\, \gamma_E - \gamma_{SE}) - \left(\frac{\partial F}{\partial E} \frac{\partial E}{\partial K_E} \right) \tag{D.6.9}$$

From (D.4.4) one gets:

$$\frac{\dot{q}_0}{q_0} = \frac{\dot{q}_S}{q_S} = \frac{\dot{q}_E}{q_E}, \tag{D.6.10}$$

and thus

$$\delta \,\$\, \gamma_0 - \frac{\partial F}{\partial K_0} = \delta \,\$\, \gamma_S - \gamma_{ES} - \frac{\partial F}{\partial K_S} = \delta \,\$\, \gamma_E - \gamma_{SE} - \frac{\partial F}{\partial K_E} \tag{D.6.11}$$

or

$$\gamma_0 - \frac{\partial F}{\partial K_0} = \gamma_S - \gamma_{ES} - \frac{\partial F}{\partial K_S} = \gamma_E - \gamma_{SE} - \frac{\partial F}{\partial K_E} \tag{D.6.12}$$

From result (D.6.12) one sees that:

$$\gamma_{ES} \nearrow \Rightarrow \left(\gamma_0 - \frac{\partial F}{\partial K_0} \right) \searrow \tag{D.6.13}$$

$$\gamma_{SE} \nearrow \Rightarrow \left(\gamma_0 - \frac{\partial F}{\partial K_0} \right) \searrow \tag{D.6.14}$$

which means that the parameters γ_{ES} and γ_{SE} have an effect in the difference between the depreciation of the capital K_0, and its marginal productivity $\frac{\partial F}{\partial K_0}$. So, the more the health and education sectors are intertwined, the better for the economy as a whole. See equation (D.6.2).

Also,

$$\frac{\partial F}{\partial K_S} \nearrow \Rightarrow \left(\gamma_0 - \frac{\partial F}{\partial K_0} \right) \searrow \tag{D.6.15}$$

$$\frac{\partial F}{\partial K_E} \nearrow \Rightarrow \left(\gamma_0 - \frac{\partial F}{\partial K_0} \right) \searrow \tag{D.6.16}$$

which means that the higher the marginal productivities for the health and education sectors are, the better for the economy as a whole. See equation (D.6.2).

An equivalent result as in (B.6.13) is valid here:

$$-\frac{\sigma(c)}{c}\frac{dc}{dt} = \delta \ \$ \ \gamma_0 - \frac{\partial F}{\partial K_0} \tag{D.6.17}$$

$$-\frac{\sigma(c)}{c}\frac{dc}{dt} = \frac{\dot{q}_0}{q_0} \tag{D.6.18}$$

$$-\frac{\sigma(c)}{c}\frac{dc}{dt} = \delta \ \$ \ \gamma_i - \gamma_{ji} - \frac{\partial F}{\partial K_i}, \quad i, j = S, E. \tag{D.6.19}$$

$$-\frac{\sigma(c)}{c}\frac{dc}{dt} = \frac{\dot{q}_i}{q_i}, \quad i = S, E. \tag{D.6.20}$$

From (D.5.13):

$$\frac{\dot{q}_L}{q_L} = \delta - \beta \ \$ \ c - \left(\frac{\partial F}{\partial L_0} \ \$ \ \frac{\partial F}{\partial L_S} \ \$ \ \frac{\partial F}{\partial L_E} \right) - \frac{u(c, \beta)}{q_L} \tag{D.6.21}$$