Proposition of a framework to reengineer and evaluate the hospital supply chain

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Proposition d'un cadre de modélisation pour réorganiser et évaluer la chaîne logistique hospitalière

L'objectif de notre recherche est le développement d'un cadre de modélisation pour permettre aux décideurs de réorganiser et d'évaluer la chaîne logistique hospitalière. Cette recherche a été motivée par une collaboration avec un hôpital belge de 900 lits qui est en train de revoir l'organisation de ses services logistiques. Les gestionnaires de cet hôpital ont l'intention de construire une nouvelle plateforme logistique qui doit regrouper en un même lieu la pharmacie, la stérilisation et le service des achats. Ces différentes unités sont actuellement situées dans des localisations séparées.

Les objectifs de ce projet de réorganisation sont la rationalisation des dépenses et l'amélioration de la qualité des soins prodigués aux patients. Cette nouvelle organisation va modifier les pratiques actuellement en-cours au service des achats, à la réception, à la distribution et à la gestion des stocks. Les unités médico-techniques, les unités de soins, le personnel et les ressources techniques seront également concernées par cette nouvelle organisation. La nouvelle plateforme recevra un grand nombre de références pharmaceutiques et devra collaborer de manière adéquate avec les différentes unités logistiques qui ont chacune leurs propres règles de fonctionnement. Nous avons choisi de nous intéresser plus particulièrement aux produits pharmaceutiques (médicaments et matériels stériles) destinés à deux unités médico-techniques, le service des urgences et le quartier opératoire. Ces deux services sont en effet critiques dans le processus de soins des patients et représentent des centres de coûts importants pour l'hôpital.

Nous démontrons que la nouvelle organisation proposée aura un impact sur le flux des produits, la distribution et la gestion des stocks et influencera également le fonctionnement des unités médico-techniques considérées. Suite aux nombreuses personnes, produits et unités concernées par ce projet de réorganisation, il est nécessaire de disposer d'un cadre de modélisation pour décrire le fonctionnement du système actuel, pour poser un diagnostic de son fonctionnement et quantifier les problèmes éventuels. Différentes solutions peuvent être proposées grâce aux modèles d'optimisation. Ces solutions seront évaluées sur base d'indicateurs de performance établis au départ d'une vision commune et partagée de la performance de l'hôpital. Cette vision commune de la performance n'est pas aisée à établir à cause des points de vue différents des parties prenantes. Une fois définis, ces indicateurs permettront aux décideurs de prendre les décisions. Ils pourront également évaluer les conséquences de leurs décisions dans le temps et dans l'espace avant leur implémentation.

Notre démarche se déroule en plusieurs étapes. Tout d'abord, nous réadaptons la définition des concepts fondamentaux de la valeur et de la performance dans le contexte de la chaîne logistique hospitalière. Nous proposons ensuite une approche pour aider les preneurs de décisions à mener un projet de réorganisation dans le domaine hospitalier et en particulier la réorganisation de la chaîne des produits pharmaceutiques en prenant en compte le flux des patients.

Le cadre de modélisation proposé sert de guide dans l'élaboration d'un modèle de connaissance basé sur la méthodologie ASCI et enrichie de la définition de la valeur et de la performance. Le modèle de connaissance a pour objectif de faciliter la compréhension du fonctionnement du système, d'identifier les activités critiques, de définir les indicateurs de

performance servant à évaluer le système sur base de mesures reflétant de manière adéquate le système de valeur de l'hôpital. Le modèle de connaissance fournit également une description des processus, des règles de gestion et l'identification des ressources.

Lorsque le modèle de connaissance a été élaboré, il est possible de développer un outil d'optimisation du flux des produits médicaux tout en considérant le flux des patients. Les demandes de produits pharmaceutiques étant très différentes dans les deux unités médico-techniques considérées, nous proposons deux solutions. Pour le service des urgences, nous évaluons l'implémentation d'une armoire automatique de dispensation des médicaments et nous proposons un modèle de gestion des stocks à deux échelons pour contrôler le système. Pour le quartier opératoire, nous proposons une approche en deux étapes. Nous déterminons le planning et l'ordonnancement des opérations chirurgicales en prenant en compte les contraintes de ressources. Nous suggérons d'utiliser une approche MRP basée sur une nomenclature aléatoire.

Les indicateurs de performance définis lors de l'élaboration du modèle de connaissance servent à évaluer les solutions proposées. Différents tableaux de bord équilibrés sont proposés pour apprécier la performance des processus considérés. De la sorte, l'approche que nous avons développée permet de s'assurer que les changements suggérés améliorent le fonctionnement de la chaîne logistique pharmaceutique et contribue à améliorer la performance globale de l'hôpital. Ce modèle a été validé sur des données provenant de l'hôpital belge avec lequel nous collaborons.

Mots clés : gestion hospitalière, modélisation, optimisation, performance

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Proposition of a framework to reengineer and evaluate the hospital supply chain

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The objective of our research is the development of a modeling framework that permits decision makers to reengineer and evaluate their hospital supply chain. This research was first motivated by a strong collaboration with a Belgian hospital of 900 beds that is currently reengineering its logistical activities. The managers of this hospital intend to build a new logistical platform to group the clinical pharmacy, the sterilization and purchasing services in a same location. These units are currently situated in separated areas.

The objectives of this reengineering project are the rationalization of expenses and the improvement of the quality of the care delivered to the patients. This new organization will change the current practices of the hospital in terms of purchasing, reception and distribution activities as well as in terms of inventory management. It will also impact the medico-technical units and the care services as well impact numerous human and technical resources. The new platform will manage a huge number of pharmaceutical references and should correctly collaborate with the different logistical units that have their different working rules. We therefore decide to focus our study on the pharmaceuticals (pharmaceuticals and medical materials) dedicated to two specified medico-technical units, the emergency rooms and the operating rooms. These units are indeed critical in the care process of patients and are major costs center of the hospital.

We demonstrate that this reorganization will have an impact upon the product flow, the distribution and the inventory management. It will also have an influence upon the working of the medico-technical units. Because numerous people, products and care units are implied in this project, we need to have a framework to describe the working of the actual system, to diagnose its working and quantify the possible failure. Different solutions can be proposed thanks to optimization models and these ones should be evaluated through the performance indicators. These indicators should be established in accordance with a common and shared vision of the hospital performance, which one is not obvious to define due to the different stakeholders' perspectives. The decision makers can then take the decision based on these indicators; they can evaluate the consequences of their decision in time and space before the implementation.

We first readapt the definition of fundamental concepts as value and performance in healthcare supply chain context. We then propose an approach that should help the hospital managers to lead such reengineering project, as the reorganization of the supply chain, mainly the medical products supply chain, while taking into account the patients' flow.

The suggested framework will provide guidance to build a knowledge model based on the ASDI methodology and enriched with the value and performance definition. The knowledge model is aimed at understanding the working of the system, identifying the critical activities, defining the performance indicators to assess the system based on metrics in accordance with the value system of the hospital, describing processes and management rules and identifying resources.

In a second phase, based on the knowledge gathered, we develop an optimization tool of the medical products flow while taking into account the patient's flow. Because the demand patterns are very different in the two medico-technical units we consider, we propose two solutions. For the emergency room, we evaluate the implementation of an automated dispensing system and we propose a two-echelon inventory management model to control this new system. In the operating room, we propose a two-step approach. We determine the planning and scheduling of the surgical operations taking into account the resources constraints and then we apply a MRP approach based on a stochastic bill of resources.

The performance indicators defined in a first step will serve to assess the proposed solutions. Different balanced score cards will suggested to capture the performance of the considered processes. Doing so, the proposed approach will ensure that the suggested changes improve the working of the pharmaceuticals supply chain and contribute to the global interest of the hospital. For illustration purposes, we experience our models on a pedagogical data set derived from a real life application encountered in the Belgian hospital mentioned above.

Key words: health care management, modeling, optimization, performance evaluation

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Chapter 1. Introduction

1 *Health care funding and supply chain*

Health services have always been an important area for applications of Operational Research. Improving the quality of services by considering limited resources is a major challenge for operational researchers (Rauner et al. 2003). According to Flagle (Flagle 2002), the founding events happened after the Second World War. In the USA, the Hill-Burton legislation of 1945 set the basis to fund innovation, construction and renovation of hospitals. The American government was committed to take responsibility for funding of needed medical care facilities. In Great-Britain, the party in power at that time set up the publicly funded National Health Service (NHS) to provide universal coverage of care. In France, the "Thirty Year Boom after the World War II" was characterized by the generalized health insurance and the French hospital development (Couanau 2003). In most industrialized countries, similar trends were observed. These acts cheered the OR community research to have interest in the optimization of the health care services.

At the beginning, the studies were focused on the efficient use of resources ultimately under a service constraint. The assets under study as the medical personnel, the operating rooms and the beds, are directly implied in the production of care, the patient's treatment.

The trend is now more focused on service optimization under constraints of resources. Policy maker has put the emphasize on the quality of services; patients claim more rights to access the health care services and the demand for care is increasing with the growing number of elderly people in the population. Indeed, since the beginning of the 1990's, the health care sector has known numerous market-driven changes in order to control the surging costs of care. The Figure 1 shows the evolution of the health care expenditure in some industrialized countries. The national governments have attempted to limit the health care expenditures by moving from a cost-based system to a revenue-based system (Orloff et al. 1990). As a result, the hospitals have now to justify the expenses to receive the funding. They have to prove the activity with a system based on the number of patients treated and their pathology. These elements put more pressure on the health service quality with limited resources.

There are however differences between the countries. To better understand the context with which the hospitals have to deal to find solutions to reduce their costs while keeping a good quality of care, we will review the socio and economical context of the health care systems in some European and North American countries.

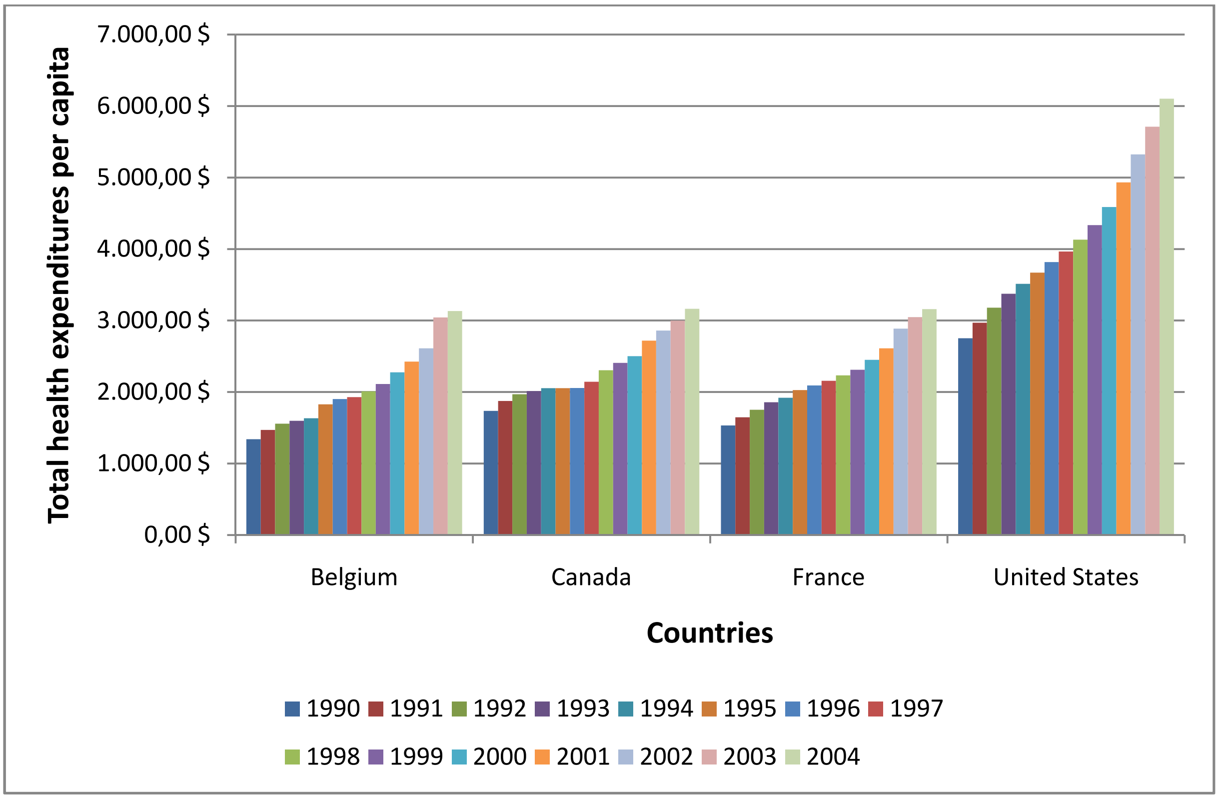

Figure 1. Total health expenditures per capita (Source: OECD Health data 2006)

1.1 Socio- and economical context of some health care systems

1.1.1 Characterization

Based on a report of the World Health Organization (World Health Organization 2000), performance of health care systems can be evaluated in terms of who may be treated (access to care), for how much money (costs of care) and with what expected outcome (quality of care). Every health care system has to find the trade-off among access, costs, and quality. The factors influencing these issues are the financing and the providing of care (Wolper 2004).

a. Financing

The financing of the health care system deals with how the money is gathered from the citizens to fund the health care system. The World Health Organization identifies 5 ways of revenue collection for health care financing, namely, general revenue (taxation), social health insurance, voluntary or private health insurance, out-of-pocket payments, and internal donations (World Health Organization 2004). These 5 ways of financing health care introduce another distinction, between private or publicly funded health care. Publicly funded health care systems are usually financed entirely or in majority part by citizens' tax or via compulsory social health insurance. Privately systems are funded through private payments made to insurance companies or directly to health care providers.

The choice for a government amongst these types of financing translates the will to provide universal access to care or not. The general access to care is ensured by taxation or compulsory social and private insurance. When taxation is the primary means of financing health care, everyone receives the same level of coverage regardless of their ability to pay, their level of taxation, or risk factors. In compulsory insurance models, health care is financed through a "sickness fund", which can receive income from a number of places such as employees' salary deductions, employers' contributions, or top-ups from the state. This general access does not come however without some rationing and limiting access to secondary and tertiary health care.

b. Provisioning of health care

The collected funds served to fund physicians and the health care institutions, as hospitals, nursing homes, convalescence centers. Their financing is broken out into two aspects: direct versus indirect provision of health services.

Direct financing of health services occurs if the main health insurer or government owns health care facilities and employs health care professionals. Indirect financing occurs if the main insurer or government contracts for the provision of various health care services.

1.1.2 Comparative analysis of health care systems

The financing and provisioning of health care will serve to characterize the health care system of some countries: Belgium, France, Canada and the USA.

a. Compulsory insurance models for indirect provision of health services - the Belgian and French health care systems

Both Belgium and France have a compulsory social insurance. Each citizen has to be affiliated to a sickness fund. The sickness funds of both countries are not-for-profit entities under public law. They use the revenues from the members' premiums to finance collective contracts with providers (hospitals, physicians) for health service to members. The contracts that are negotiated between the payers (sickness funds) and the providers (hospitals) are fixed and static in order to provide a standardization of the conditions of health care benefits and delivery (Saltman et al. 2004).

Hospitals in Belgium and in France are part of this social health insurance, regardless of ownership. They have all to take part to the public service and care patients.

In Belgium, hospitals are mainly public (60%) and private not-for-profit (40%) (Saltman et al. 2004). The law of the 7th of August 1987 describing the health care system in Belgium and its executor decisions describes the organization, working and financing rules of hospitals (Ceuterick et al. 1998). Each Belgian hospital, public or private-not-for-profit, receives a funding from the State to face the operating costs of the admission and stay of the patients in a hospital. Before 2002, the financing system was based on a fee-for-service reimbursement to face the hospitalization expenses. The law of the 14th of January 2002 introduced a prospective payment system, the casemix-based financing method based on the APR-DRG (All Patients Refined Diagnosis Related Group). The “Résumé Clinique Minimum” (RCM) or “Minimum Clinical Summary” details all the procedures and drugs received by the patient during his hospital stay. This data allows a detailed description of the casemix of each hospital, the grouping in homogeneous patients groups being done with the APR-DRG software. The objective of this database is to compare, case by case in all Belgian hospitals, resource utilization and to develop tools to rate resources utilization and quality of care. These data are used by the Ministry of Health to dispatch the resources equitably among all hospitals.

In France, hospitals are public (65%), private for-profit (20%) and private not-for-profit (15%). As in Belgium, all hospitals have to participate to the public service. Public and private not-for-profit hospitals have the same working rules and are funded on the same basis. Sole the personnel have different status. The private hospitals are authorized to make profit; they can fix the price and choice the most profit making activities. As a consequence, most of them are specialized in acute care.

The French ordinance number 96-344 of the 16 April 1996 defined the hospital financing: from one side, the public and private not-for-profit hospitals received a global endowment. A global budget for reimbursed health care is voted annually by the parliament to allocate to the different French regions. The regional hospitalization agencies were created in order to better organize the supply of hospitals beds at the local level and to determine the global endowment of each hospital of a specific region. From the other side, the private for-profit hospitals received a financing that didn’t include the medical fees and were funded on basis of a daybed allocation.

The new funding system, the ‘T2A’, is part of the “plan hospital 2007” and is based on a system of prospective payment. All hospitals, public or private, receive money to cover their operating costs based on a casemix-based financing as in Belgium.

In both countries, the role of the State is preponderant. The basis of the health care system enforced is the maximum social solidarity between citizens and to have universal care coverage. As a result, the system has nearly no competition between the providers to ensure good access and service to patients.

b. Tax-funded model for indirect provision of health services - the Canadian health care system

Canada indirectly provides health services through tax-funded public system, which is accessible to all Canadians. Most hospitals in the country are nonprofit, autonomous entities that provide inpatient and ambulatory services, diagnostic testing and other services.

There is a single, government-operated provincial health plan that is the sole payer for hospitals and physician care. The government monitors the levels of health performance and has taken different measures to control costs (implicit and explicit rationing of services).

c. Mixed models for provision of health services – the US health care system

The US health system has not achieved universal access to health insurance but is based on a voluntary access; it means that the USA has declared health care as a right but rely on public and private systems of care. The basis of the system was to minimize individual losses since the society is based on an individualistic self-interest; this system attempts to spread risks across individuals and exclude those with exceptionally high risk potential.

The federal government is the single largest health care insurer and purchaser. This system is based on a mix of employer-based private insurance subsystem, social health insurance for the elderly, and tax-funded. There is Medicare, a national social health insurance program, which provides covers health services for the elderly, the disabled, and those with end-stage renal disease. This system is financed by payroll taxes. Medicaid is a joint federal-state health benefit program that covers targeted groups of the poor as pregnant women and is financed by federal tax revenue. The state children's health insurance program (SCHIP) is a state-federal health benefit program targeting poor children. It is funded by federal and state taxes. Private insurance is provided by not-for-profit and for-profit health insurance companies and regulated by state insurance commissioners.

The provision of care is direct and indirect. Hospitals are for-profit, not-for-profit and public and are paid by a combination of methods: charges, per-admission rates and capitation. In terms of care quality, the hospitals have been concerned about medical errors and reduced services. Practically all US hospitals have established continuous quality improvement program in order to comply with voluntary standards imposed by accrediting bodies such as the Joint Commission on Accreditation of Health Care Organizations (http://www.jointcommission.org).

To control the costs, the United States has deployed managed care within employer-based insurance market and has mandated various cost containment measures in both its health programs, Medicare and Medicaid. At the same time, the third-party payers and private insurers' attempted to control costs growth through a combination of selective provided contracting and discounted price negotiations. The results of these measures have been shifting the costs on the patients, increasing the premium and out-of-pockets expenses.

d. Summary

The considered countries have different socio-economical contexts of health care system. The Table 1 presents a summary of these systems.

The US health care system faces more competition than any other health system in the world (Porter et al. 2006), which should lead to a cost effective system. However, the number provided in the Figure 1 show the other way round, with a cost per capita the highest. Some explanations are that the costs of treatments are higher since the health care is based less on preventive than curative medicine. The US Government was the first to take measures to control the rising costs of care by introducing a prospective payment system. The USA was then followed by Canada, Belgium and France. Even if these countries perform better to keep the costs of health care under control and provide a good quality of care to the citizens, they are constantly struggling to find solutions as the recent headlines in France remember us with the "Larcher's report" (Le Figaro, 7th of April 2008).

Table 1. Comparison table of the health care systems

Countries	**USA**	**Canada**	**France**	**Belgium**
Financing of the health care	Mixed	Tax-funded	Compulsory insurance	Compulsory insurance
Provision of care	Indirect	Indirect	Indirect	Indirect
Hospitals	Public Private not-for-profit Private for-profit	Mainly public hospitals	Public Private not-for-profit Private for-profit	Public Private not-for-profit
Government influence	Restricted	Very high Direct	Very high Indirect	Very high indirect

In such a context, hospitals are looking at their cost structure to identify the highest expenses. According to some studies, the cost of logistical activities (products and personnel costs) can be as high as 30 to 40% of the total annual budget (Chow et al. 1994). Supply chain (SC)/logistical activities have been therefore receiving a growing interest from the researchers as a way to reduce the costs while providing a good quality of care.

1.2 Organizational structure

The logistical organization and the organizational arrangements are viewed as an influencing factor of the hospital performance. Indeed, as underlined by (Drucker 1954),

"a good organization structure does not by itself produce good performance – just as good constitution does not guarantee great presidents, or good laws, or a moral society. But a poor organization structure makes good performance impossible, no matter how good the individual managers may be. To improve organization structure… will therefore always improve performance".

The need for a given type of organization depends on how logistics costs are incurred and where service needs are the greatest. The administrative organization is defined by Ballou (Ballou 2004) as the structure that facilitates the creation, the implementation and the evaluation of plans. It is the formal or informal mechanism for allocating the firm's human resources to achieve the goals. The organization structure coordinates the decision making of separate logistical activities. It defines the lines of authority and responsibilities to ensure that goods are moved according to plan and that replanning is carried out when needed.

Hospitals organize their logistical/supply chain activities in different ways. We present the organization types of hospitals we visited in the USA and in Belgium and filled in with information found on the internet. We briefly describe these organizations and we try to characterize these different ways of organizing the logistical activities. We also try to determine how this organization influences the performance. To do so, we use the parameters proposed by Ballou (Ballou 2004). He characterized the logistical/supply chain activities by 3 attributes.

1.2.1 Organization structure: type of structure needed

The organization structure deals with the kind of organizational arrangement that is made to handle product and service movements. Three types can be identified:

1. The informal organization is a more traditional organization of logistical activities where these ones are split between the primary functions of finance, operations and marketing. There is no formal way to coordinate planning and control that are made more through coercion or persuasion;
2. The semi formal organization is a matrix organization where the logistics/supply chain manager is responsible for the entire logistics system but he does not have direct authority over the component activities;
3. The formal organization gives clear lines of authority and responsibilities to the logistics/supply chain manager who is most of the time higher in the hierarchy.

1.2.2 Organizational orientation

The organizational orientation is depending upon the type of corporate strategy chosen by the firm for the logistic supply chain among the process strategy, the market strategy and the information strategy.

1. The process strategy adopts a cost strategy, by trying to achieve the maximum efficiency in moving goods/service throughout the supply chain;
2. The market strategy puts the emphasis on the customer and manages together logistical activities relating to customer service;
3. The information strategy emphasizes the coordination of logistics activities through the information system.

1.2.3 Organizational positioning

The organizational positioning concerns where to place the logistical activities in the organizational structure. This is determined by such issues as decentralization or centralization, staff or line positioning and large company or small company.

1. The decentralization versus centralization question is about whether the activities should be grouped close to top management or dispersed throughout the divisions. A centralized organization groups logistic activities at the corporate level for serving all departments while the decentralized organization puts the responsibilities for logistics at the division level;
2. The staff versus line positioning of logistical responsible determines the responsibilities and the negotiation power of the logistical manager. If he is in line position as other responsible of line functions as operations, he has a direct responsibility; if he is in staff position, he will have an advisory, consulting role;
3. The large versus small distinction is more about the size of the company/hospital. In bigger system the logistical function is most of the time more clearly defined and structured to face a greater activity level.

1.2.4 Examples of organizations within hospitals

We combine the information we gather through our visits in hospitals and found on internet to find out how health care centers are organizing their logistical/supply chain activities. The first comment we have to do is that we found few hospitals with a “logistic” or “supply chain” department. In North America, most of the time, logistical activities are grouped in what they call the “materials management” department. In France, these activities are grouped under the responsibility of the “economical department”. We present hereunder the information we got about the organization of comparable hospitals, university hospitals, one American, one Canadian, two French and a Belgian, that have each more than 15000 admissions a year.

a. An American hospital

The Figure 2 schematizes the materials management organization of the Syracuse State University hospital, New York, (Syracuse Hospital 2007). This kind of organization is common for American University hospitals. This organization is also adopted by the UW hospital in Madison.

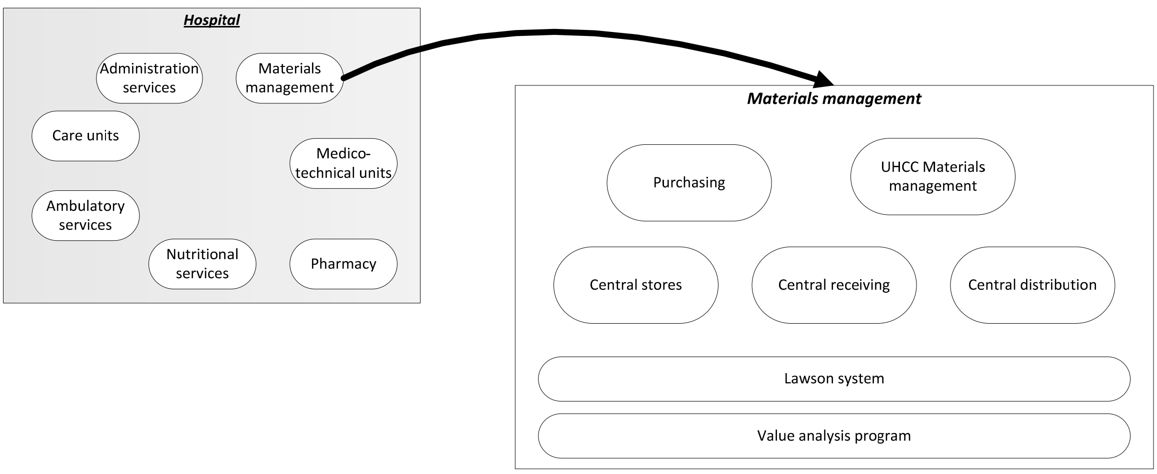

Figure 2. Hospital organization (Syracuse, NY, USA)

The materials management department is considered on the same hierarchical level as the other units of the hospital as the care units, the medico-technical units and the pharmacy. The material management groups all traditional logistical functions as the purchasing, storing and distribution of the items (supplies, equipment and services) used throughout the hospital. It has the authority to issue contracts and purchase orders on behalf of the hospital. It is also responsible for the medical and surgical supplies (UHCC Materials management). The inventories are centralized is that area.

The materials management department is supported by an information system (Lawson) that manages the information with the users department for requisitioning, purchasing, receiving and inventory control.

The department also sets up a process, the “value analysis program”, to oversee the evaluation and acceptance/rejection of new and existing products and equipment in order to start a standardization process of the products used.

b. A Canadian hospital

The supply service of the hospital of Laval (Hospital-Laval 2007) is part of the activities of the administrative and support services, as highlighted in the Figure 3.

This organization puts the service in staff positioning giving it a more consulting role. As its counterpart in the US, the supply service is responsible for the acquisition, stocking and distribution of supplies, equipment and services necessary within the framework of their activities. The service also negotiates and carries out acquisition on its own.

The information system used to manage the product is based on the code-bars technology and of the doubles racks system.

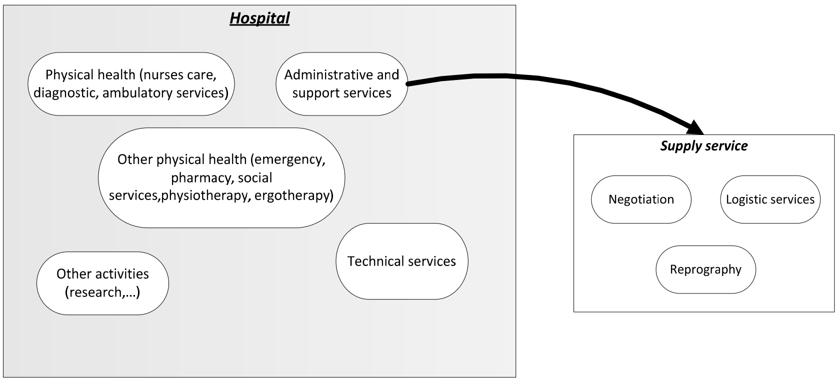

Figure 3. Hospital organization (Laval hospital)

c. The French hospitals

We also present the organization of two French hospitals, one with a more “traditional” organization, as illustrated in Figure 4, and the other one having adopted the structure suggested by the French health care legislation, as illustrated in Figure 5.

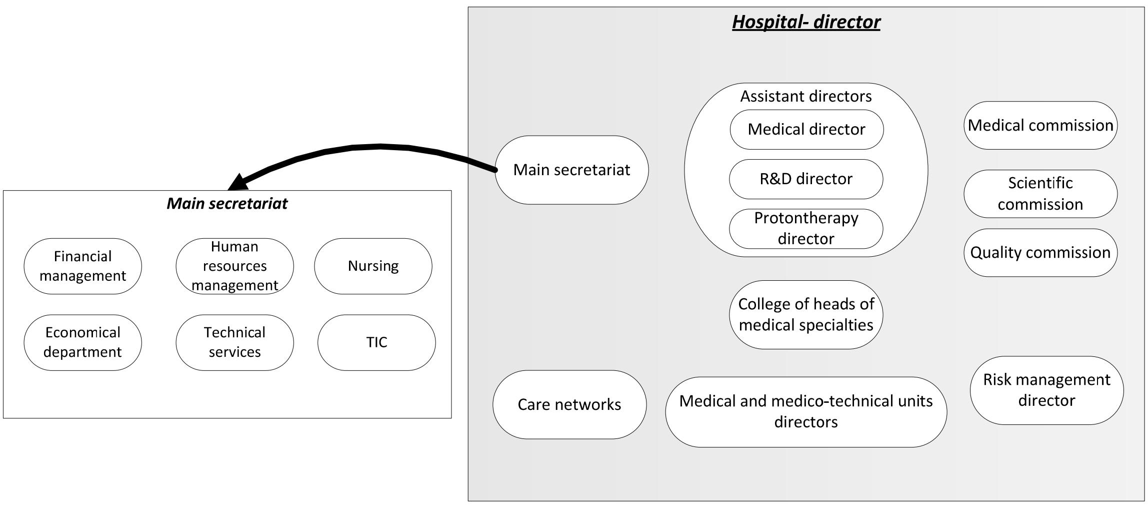

Figure 4. Pierre et Marie Curie Hospital

The first figure represents the "traditional" hospital organization as it was wide spread in France but also common in Belgium. The related functions of logistics are mainly in the economical department under the responsibility of the secretariat, in staff positioning in the hierarchy. Some of the logistical functions are also done by other departments as the finance department. The economical department is responsible for the infrastructure, purchasing and supplying. The main functions in order of priority are the food and laundry services, the supply of medical needs, reception, stock management, purchasing, services, distribution and transportation. In addition, each care unit has also its own economical ward.

The second organization is the one as suggested by the "Plan hospital 2007". The "Plan hospital 2007" is a modernizing plan of the French hospitals based on a new funding system, the "T2A", and on new governance. The "T2A" is a system that allocates subsidizes to the hospital based on its activity. The new governance aims at improving the hospital performance and using more efficiently the resources. The logistical function is one of the areas of activity, providing support to the care units. It focuses on the patient's flow, suggests the mutualization of shared resources, the grouping of activities in medical clusters and the development of a contract approach between each area of activity to promote a more efficient working.

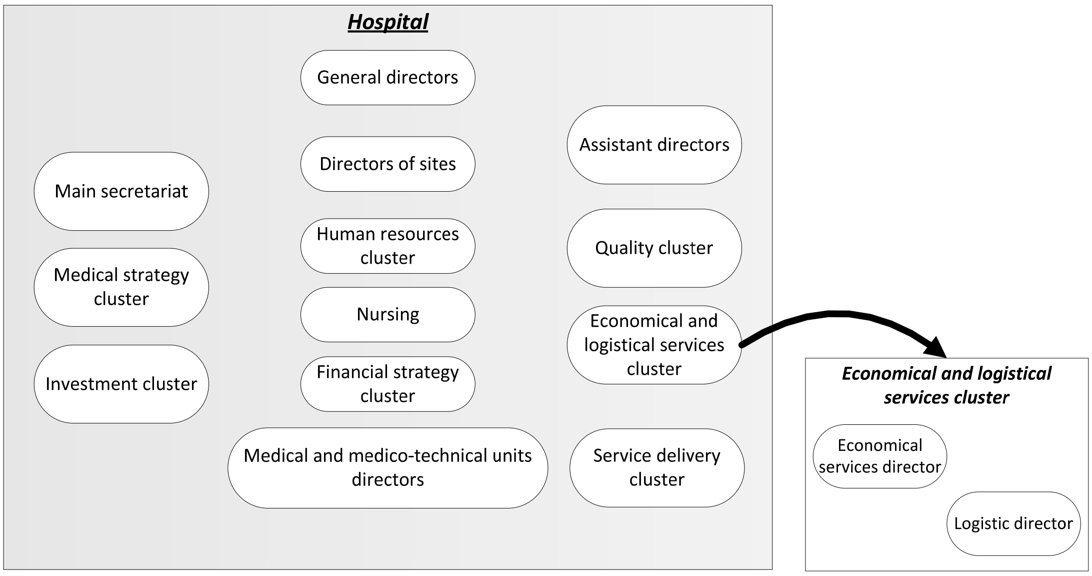

Figure 5. CHU Rouen (CHU-Rouen 2006)

d. The Belgian University hospital with which we are collaborating

The Belgian University hospital of our interest has its logistical activities spread out between different departments as it is the case in traditional French hospitals. The different logistics functions are under the responsibility of the administrative director or the technical director. The pharmacy and the sterilization have different information systems. The sterilization and the purchasing are supported by a same software to manage the inventory and the ordering.

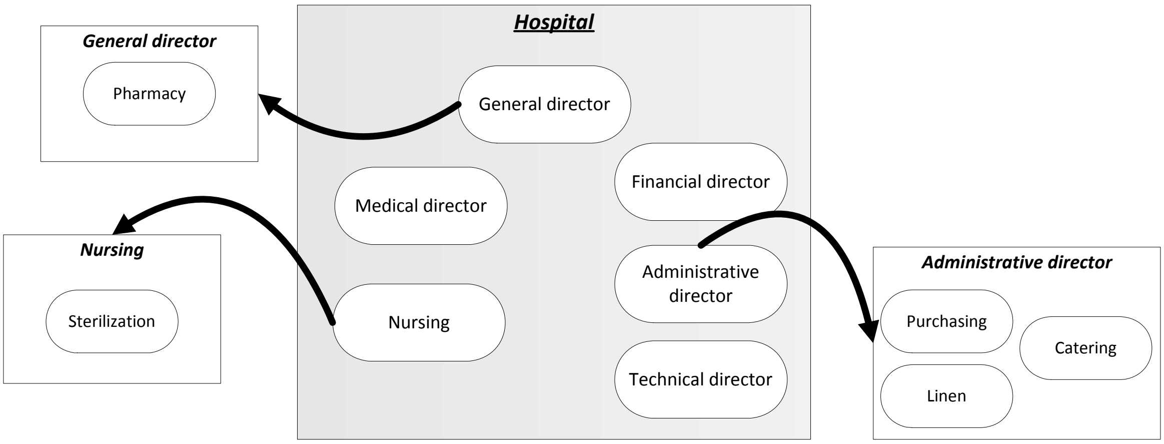

Figure 6. Belgian University hospital

e. Comparisons

The different organizations we found illustrate the variety of logistical/ SC organizations that are adopted in the hospitals. The Table 2 presents a summary of this information.

Table 2. Summary of hospital organizations

	US hospital	*Canadian hospital*	*French hospital (traditional)*	*French hospital (T2A)*	*Belgian hospital*
Organization structure	Formal	Formal	Informal	Semi-formal	Informal
Organizational orientation	Process	Process	Market	Market	Market
Organizational positioning	In-line Centralized Large	Staff Centralized Large	Staff Decentralized Large	In line Centralized Large	Staff Decentralized Large

These structures have an impact on the system performance. In the USA, the Materials Management department is an important unit, setting up partnerships with external suppliers to have an integrated approach for the materials supply. The suppliers are even part of the system. Hospitals also tend to set up just-in-time policies and EDI to share information with the providers. However, this high dependency towards external sources is not without any danger and there is now a trend to be more independent.

Both hospitals we consider for North America adopted the same organizational structure (excepted for the organizational positioning of the materials management department). Their supply chain seems to be efficient, having led to a drastic reduction of inventories compared to their European counterparts.

For French and Belgian hospitals, the organization was firstly more decentralized, with an economical department having subsidies in each medico-technical unit. As underlined in the paragraph 1.2., the health care system aim was to provide good care for every patient. This decentralized organization led to an increase in the amount of stock and the information systems developed were parceled or very basic. The trend is now towards more centralization.

These different organizations have an impact on how the supply chain activities are managed and coordinated. In a more centralized setting, it is easier to put in place integrated approaches from the suppliers to the care units. The manager has more power upon the activities and can have a global view.

1.3 Definition of health care supply chain/logistics

The diversity of logistical/supply chain organizations and activities that are grouped under this name doesn't easy the statement of a definition. In addition, this area of activity has known so far a big evolution. For some reasons, researchers have not attempted to examine the logistical operations of health care and make comparisons to the logistical processes in other industries. The health care logistical community has also either not recognized the similarity or made the comparison between the manufacturing products and the provision of care to patients (Jarett 1998).

However, both are close environments. Although the health care industry is considered a service industry, the industry cannot be catalogued as either a service or manufacturing organization based upon these definitions and differences. First, health care providers are not able to inventory their services and also do not provide the limited service or product line that most service organizations provide. Second, health care providers must maintain distribution and inventory systems similar to but often more complex than those in the manufacturing industry. Third, the health care industry can only project production outputs based on their current daily patient census. Fourth, health care inventories may be composed of 50,000 to 400,000 stock-keeping units (SKUs) and the product requirements change frequently. A military organization during a period of conflict is the only organization that requires a logistical environment as complex and flexible as that required by the health care industry (Jarrett 2006).

We thus start from the logistics as defined in the industry. It is defined as ''the coordination of supply, production and distribution process in manufacturing systems to achieve a specific delivery flexibility and delivery reliability at minimum costs''. Translated to health care organizations, it comprises the design, planning, implementation and control of coordination mechanisms between patient's flows and diagnostic and therapeutic activities in health service organizations (Beaulieu et al. 2002).

This definition puts the emphasis on the processes, focusing on the patient's flow. It doesn't take however into account the management of the returned products that can be of high importance in the health care, the reverse logistic, nor the information flow that is of primary importance to ensure the coordination between the different activities and the traceability of the delivered products. Hassan (Hassan 2006) fills in the definition with the delivery and return management from the supplier to the end customer (the patient). These activities are triggered by the patients. The information flow ensures the coordination between the different partners.

Through the introduction, we have underlined the importance of the financial constraints and resources shortage that put the health care industry under pressure to satisfy the clients under the constraints of resources. Mabert et al. (Mabert et al. 1998) propose a definition focusing on the output of the health care supply chain. This definition states that the goal of the logistical/SC health care activities is to maximize output/throughput with available resources, taking into account different requirements for delivery flexibility (e.g. differentiating between elective/appointment, semi-urgent, and urgent delivery) and acceptable standards for delivery reliability (e.g. determining limits on waiting list length and waiting times) and acceptable medical outcomes. This definition puts a clear emphasis on the links that exists between the performance of the hospital supply chain and the performance of the care.

While focusing on the aspect of the performance in the health care, Griffith (Griffith 2000) underlines the difficulty to define it since it is not so obvious to identify the client. The patient is indeed not necessarily the final consumer. If we take the examples of the medicine administrated to the patient during his stays, he has little to say regarding the products he will receive. The nurses or the physicians are using them and the facilities of the hospital to provide a care to the patient, who will be the indirect consumer in that case. Related to the service, the patients and the care personnel have different expectations. These differences result in different perception of the service performance.

Considering the different definitions we have found in the literature, we suggest to define the hospital supply chain/logistics activities as the activities of design, planning, implementation and control of coordination mechanisms between patient's flows and diagnostic and therapeutic activities in health service organizations. Different actors (patients, care personnel, management) are implied in these activities and have their own goals. The activities resources are human, materials and financial and are in limited supplies. The information has to ensure the coordination between the different actors of this supply chain and has to ensure the traceability of the activities and products. The objective is to maximize output/throughput under the resources constraints, taking into account the different actors' requirements for delivery flexibility and reliability and acceptable medical outcome.

This objective is critical for hospitals that are competing now in a consumer market and that are under financial pressure. Satisfying the different stakeholders' expectations to meet achievements both in service to the society and staying profitable is not obvious for hospitals, as well as for the hospital with which we are collaborating and to which we will refer throughout the different cases illustrated in this dissertation.

2 *Research motivation*

We were interested in the health care supply chain and we get the opportunity to start a collaboration with a Belgian hospital of 900 beds that is currently reengineering its logistical activities. The managers of this hospital intend to build a new logistical platform to group the clinical pharmacy, the sterilization and purchasing services in a same location. These units are currently located in separated areas as shown on the Figure 7. The pharmacy manages the drugs and pharmaceuticals, the sterilization has under its supervision the metallic and the sterile material and the non sterile material dedicated to the care, and the purchasing department handles the general supply for the hospital. The management wants to locate that new platform in the basement of the care units.

The objectives of this reengineering are the rationalization of expenses and the improvement of the quality of the care delivered to the patients. This new organization will change the current practices of the hospital in terms of purchasing, reception and distribution activities as well as in terms of inventory management. It will also impact the medico-technical units and the care services as well influence numerous human and technical resources. The new platform will manage many pharmaceutical references and should correctly collaborate with the different logistical units that have their different working rules. We therefore decide to focus our study on the pharmaceuticals (pharmaceuticals and medical materials) dedicated to two specified medico-technical units, the emergency rooms and the operating rooms. Both these medico-technical units have very different demand patterns for the pharmaceuticals. The reasons underpinning that choice are legal, economical and qualitative.

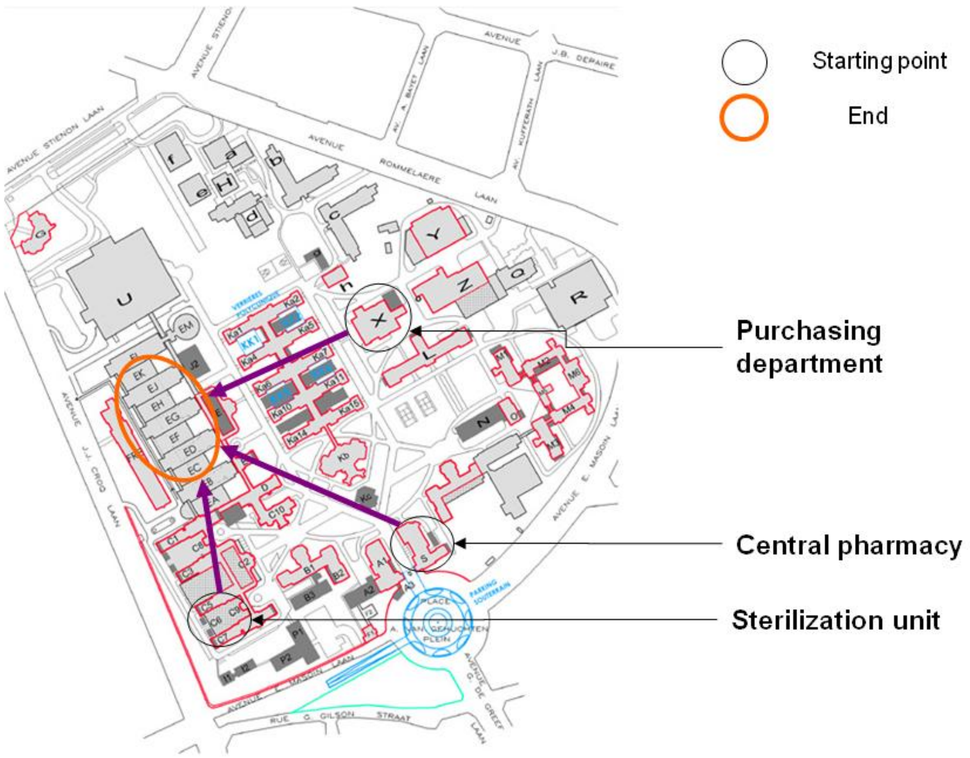

Figure 7. the BelgianHospital map

From the legal point of view, the law governs the pharmaceuticals dispensing in Belgium. The medicine has to be delivered based on a name and on a prescription. There are however some exceptions to this rule for units dealing with emergency cases: these units are allowed using a dispensing cabinet. These cabinets are replenished globally, without using a priori prescription. These medical cupboards are set up in care units like emergency rooms, intensive care units, operating rooms, neonatology, delivery rooms, medico-technical units and doctor's office. For all these rooms, an inventory of medicine might be kept to satisfy any demand and there is room to apply supply chain management concepts to improve the management of the products.

From the economical point of view, the costs of the pharmaceuticals and medicines amount to a significant part of hospital expenditure, up to 15% of a French hospital annual budget (Delomenie et al. 1996). In the hospital we are collaborating with, the pharmacy amounts for more than 15% of the total hospital budget. According to hospital managers, the pharmacy is also the third revenue provider. The operating rooms (OR) are one of the main cost center of the hospital, consuming more than 10% of the total budget (Chaabane et al. 2007) and studies done on the costs structure of a surgical procedure show that the costs implied by the surgical acts are the highest (Rossi-Turck et al. 2004). Amongst these costs, there are the medical supplies (pharmaceuticals, sterile material and working of the room). Concerning the emergency rooms, there are facing increasing pressure on their budget because of the increasing demand for emergency consultancies coming from people without insurance coverage and of the cost reduction imposed by the management; there is therefore the need to optimize the working of these units and to find savings (O'Shea 2007).

From the qualitative point of view, pharmaceuticals flow is critical because of the nature of the product (patient's life-related) and because it is directly implied in the care of the patients; the pharmaceuticals have to be available in the right amount at the right time. In the OR, if the pharmaceuticals are not available, it can cause a postponement of surgical procedure triggering planning trouble and/or hazard of patient's health. In the emergency rooms (ER), it can cause the death of the patient. The ER is also one of the first contact points of the patient with the hospital and sets the quality perception of the patients.

The reorganization project undertaken by the Belgium hospital has pointed out a number of questions, in different areas:

- Performance
    - What are the costs/benefits of the implementation of this new platform?
    - What is the impact of this new way of working upon the quality of care?
    - What are the savings?
    - Is it suitable to only consider financial indicators?
    - What are the different elements to evaluate appropriately the performance? What to measure? Who is responsible?
- Platform sizing
    - Which products should be stored?
    - How much space should be dedicated for which use?
    - How the available space should be allocated to the different units? (pharmacy - sterilization and purchasing)?
- Supply chain management
    - Which inventory management policy should be applied to which product?
    - Which inventory system should be put in place? An automated dispensing system, a kanban system?
    - Where the inventories should be located? How many quantities of each product should be hold on hand?

- What service level should be asked for?
- How the products supply should be organized?
- How the relationships with the suppliers should be handled?
- What size should be the logistical platform?
- Can the different products be stored together?
- How the products delivery should be organized?
- Are the different products flows compatible? Can they be grouped together in a same delivery?
- What kind of containers should be used to distribute the products?
- How to ensure the coordination between the products flow and the patients flow?

These questions once answered will generate a new organization of the hospital. This will have an impact upon the products flow, the distribution and the inventory management. It will also have an influence upon the working of the medico-technical units. Because numerous people, products and care units are implied in this project, it is needed to have a framework to describe the working of the actual system, to diagnose its working and quantify the possible failures. Based on the knowledge acquired through the description of the system, we want to propose improvements for the pharmaceuticals dispensing of these two medico-technical units. We then need to come up with pertinent optimization models and solve them accurately to achieve suitable solutions. These solutions need to be assessed through measures to judge the improvement in the performance of the current system. However, the definition of the hospital performance is not obvious. This notion is multidimensional. Indeed, the performance metrics are the reflect of the hospital objectives that can be conflicting depending on the point of views of the different stakeholders.

We devote an important part of this research to clearly define the performance and establish the indicators and the scorecards. Once the performance definition set, the optimization solutions we will proposed focus on the supply chain management, mainly the inventory management and the planning of activities. At the time we started the study, the platform sizing was already fixed by the management and we had to consider it as a constraint. When the solutions are proposed and assessed based on the defined indicators, the decision makers can take the decisions; they can evaluate the consequences of their decisions in time and space before the implementation.

Chapter 2. Literature review

1. Modeling approaches

As we mentioned it in the previous chapter, we need a framework to describe the current system working and to lead the needed changes. Due to the complexity of the supply chain, modeling methodologies are needed to identify and lead the changes. Different methods/methodologies exist and share the same approach: firstly, the actual system is modeled to describe the current way of working (AS-IS situation); then, the targeted system is developed to build the appropriate planning and control system and to evaluate the expected performance after the implementation of the proposed solutions (TO-BE description).

We have a look at the different methods and methodologies that were already applied to the health care sector. Firstly, we give some definitions about the terminology used, based on the GERAM concepts (Force 1998). GERAM, Generalized Enterprise Reference Architecture and Methodology, is a generalized framework that provides a description of all the elements recommended in enterprise engineering[1]. It sets the standard for collection of tools and methods from which any enterprise would benefit to more successfully tackle initial integration design, and the change processes which may occur during the enterprise operational lifetime. Secondly, we present the different methods that were already applied to the health care sector.

[1] Enterprise engineering is defined as the discipline that "organizes the knowledge that is needed to identify the need for changes in enterprises and to carry out that change expediently and professionally" (ISO WD15704).

1.1 Definitions, based on the GERAM framework components

a. Enterprise engineering methodologies - EEM

(EEM) describe the processes of enterprise integration of projects, as for instance a merger or a supply chain integration project. An enterprise engineering methodology may be expressed in the form of a process model or structured procedure with detailed instructions for each enterprise engineering and integration activity. These methodologies use ***Enterprise modeling languages*** (EML) to describe and model the structure, the content and the behavior of the enterprise entities in question.

EMLs define the generic modeling constructs for enterprise modeling adapted to the needs of people creating and using enterprise models. In particular, enterprise modeling languages will provide constructs to describe and model human roles, operational processes and their functional contents as well as the supporting information, office and production technologies. To build an enterprise model, several modeling languages could be needed.

b. Enterprise Models- EM

EM represent the particular enterprise. Enterprise models can be expressed using enterprise modeling languages. EM include various designs, models prepared for analysis, executable models to support the operation of the enterprise, etc. They may consist of several models describing various aspects (or views) of the enterprise.

c. Enterprise Engineering Tools - EET

EET support the enterprise engineering methodology and modeling languages. Engineering tools should provide for analysis, design and use of enterprise models.

d. Partial Enterprise Models - PEM

PEM - (reusable-, paradigmatic-, typical models) - capture characteristics common to many enterprises within or across one or more industrial sectors. Thereby these models capitalize on previous knowledge by allowing model libraries to be developed and reused in a 'plug-and-play' manner rather than developing the models from scratch. Partial models make the modeling process more efficient. The scope of these models extends to all possible components of the enterprise such as models of humans roles (skills and competencies of humans in enterprise operation and management), operational processes (functionality and behavior) and technology components (service or manufacturing oriented), infrastructure components (information technology, energy, services, etc.). Partial models may cover the whole or a part of a typical enterprise. They may concern various enterprise entities such as products, projects, companies, and may represent these from various points of view such as data models, process models, organization models, etc. Partial enterprise models are also referred to in the literature as ‘Reference Models’, or ‘Type I Reference Architectures’ (Force 1998).

1.2 Methods applied to hospital projects

Since there is no particular approach dedicated to the health care, we have listed methodologies coming from industrial management and that were already applied to health care problems. We classified these techniques according to the GERAM framework components.

Among the enterprise modeling languages, there are the IDEF family languages (Integration Definition) that have been developed by the ICAM (Integrated Computer Aided Manufacturing). IDEF0 (function modeling method), coming from SADT method, is based on a hierarchical decomposition of activities. An IDEF0 model represents the activities from the point of view of the business, how those business activities interrelate, resources used to conduct each activity, and the result or output of each activity. The model consists of graphics and associated text supporting the graphics. Ducq (Ducq et al. 2004) use SADT/IDEF0 to describe the different processes within a hospital. This method is useful to describe the AS-IS situation of a system during a Business Process Reengineering (BPR) approach (Kim et al. 2002b). It covers mainly the process description but it is not so easy to understand the information flows between the action diagrams.

IDEF1 (Integrated Computer aided manufacturing DeFinition) is shaped for the design of relational data bases. It models information flows. Staccini (Staccini et al. 2005) use it to map each patient-oriented process and to set up an information system that comes up to the users' expectations in terms of quality (security and traceability). This tool only focuses on the informational aspects and doesn't take into account the decision centers.

UML (Unified Modeling Language) is a standardized specification language for object modeling. UML is a general-purpose modeling language that includes a graphical notation used to create an abstract model of a system. It fits for the analysis and design of information systems. It was also designed as a communication tool, limiting misunderstanding. It was used by Staccini (Staccini et al. 2001) to create a data model for the blood transfusion process.

Enterprise modeling languages only tackle some activities of the enterprise engineering methodology like the identification of information to be used, the resources needed, the identification of responsibilities. It provides the modeler with specific point of view(s) needed for the AS-IS situation.

ARIS, along with ARIS toolset, is an engineering tool based on a modeling language, using a process view. It allows representing the different views of an enterprise (functional, informational, organizational and control) based on different levels (conceptual, technical and implementation). It provides user guidance for the modeling process. It is often used to do reengineering of information systems. ARIS tool is applied together with an enterprise methodology to lead a reengineering project. For instance, ARIS was used along with the ASDI architecture to model the AS-IS situation during the setup phase of a new hospital in France (Chabrol et al. 2006; Fenies et al. 2005).

SCOR is a process reference model, designed to model the supply chain, and developed by the Supply Chain Council (Council 2006). It provides a framework for characterizing supply chain management practices and processes that result in best-in-class performance. It is a common process-oriented language for communicating among the supply chain partners in the following areas: plan, source, make, deliver and return. It mainly describes the physical flows. It was applied to a central pharmacy to describe the pharmaceuticals flow (Baboli et al. 2005). SCOR gives the user a general view of the processes and a database (reference model) but doesn't provide a support to lead the analysis or the changes required.

To have a framework to lead a full analysis design study, enterprise engineering methodologies are needed. These reference architectures may use some of modeling techniques cited previously. They describe the process of enterprise integration and will guide the user in the engineering tasks of enterprise modeling. Different methodologies may exist which will cover different aspects of the enterprise change processes. These may be complete integration processes, or incremental changes as experienced in a continuous improvement process. Different architectures have been developed so far.

CIMOSA (Computer Integrated Manufacturing Open System Architecture), has been developed by the European CIM Architecture Consortium under ESPRIT Projects.

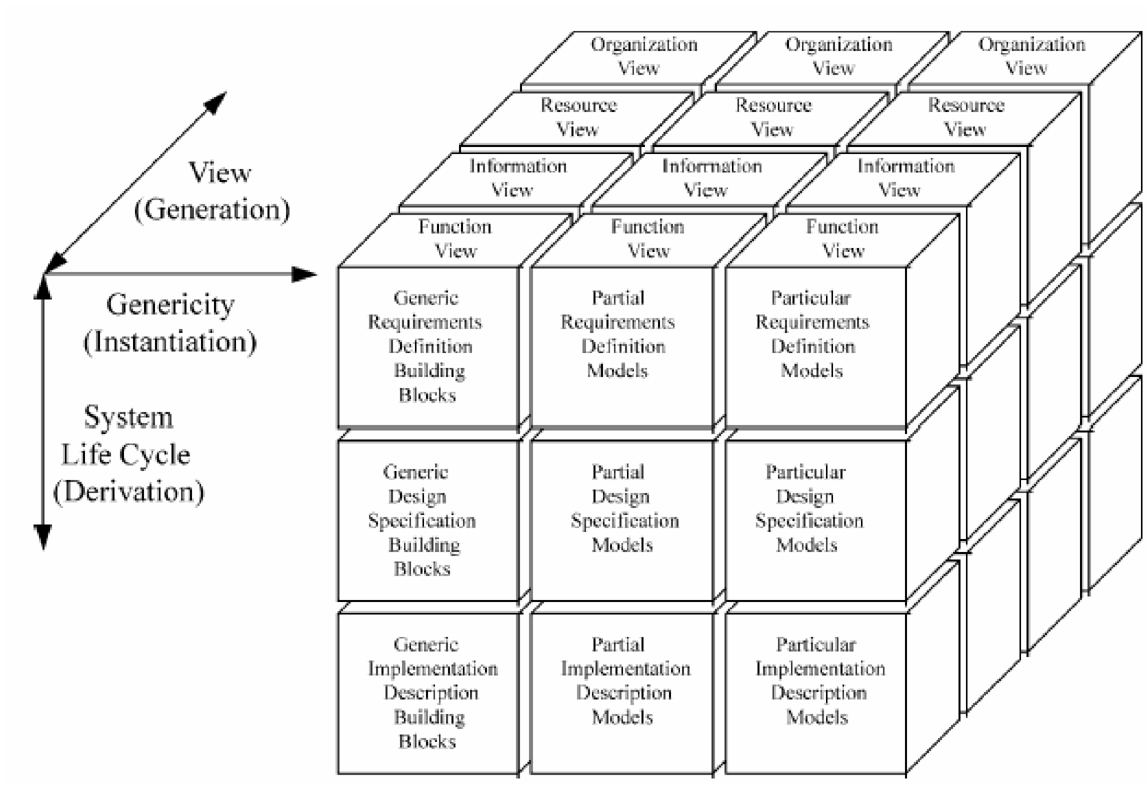

Figure 8. The CIMOSA cube.

CIMOSA has its own modeling formalism, CIMOSA cube, and methodological framework. Figure 8 shows the CIMOSA cube. CIMOSA provides a coherent modeling framework for the physical and informational flows but it is confined to the cube and the use of this architecture requires time to be familiar with it. In addition, there is no graphical formalism to represent the processes and the modeling description is based on text and is not suitable for simulation.

The GRAI integrated Methodology, GIM, (Chen et al. 1997; Doumeingts et al. 1993; Doumeingts et al. 1987) has been developed by the Grai Laboratory of the University of Bordeaux in France (Doumeingts et al. 2000).

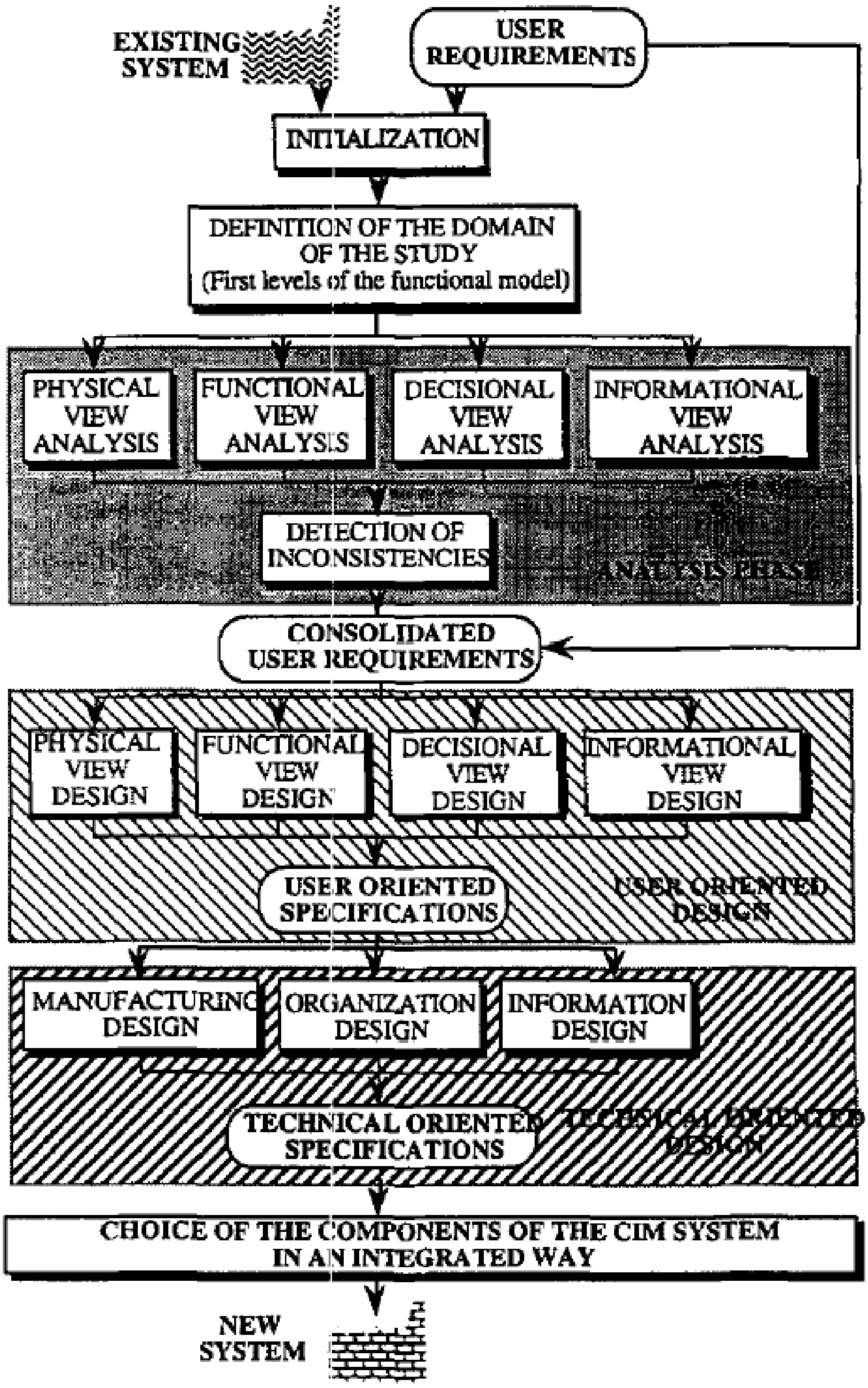

Figure 9. GIM structured approach (Chen et al. 1997)

Figure 9 illustrates the different steps of the GIM methodology. It enlarges the modeling capabilities of GRAI by adding to the decision modeling, the modeling methodology for processes, information and physical infrastructure. Different modeling languages are used like IDEF0, the GRAI grid and MERISE.

We haven't so far illustration of the application of GIM to set up a hospital. However the GRAI grid and GRAI network were applied in different projects to set up the decision and control system in hospitals (Besombes et al. 2004; Ducq et al. 2004). The GRAI grid is a tool to describe the decision system according to two axes, the time and the decision description while the GRAI network is a tool to represent the decision activities.

These two architectures, CIMOSA and GIM, are each linked to specific software. While providing the user with a framework, they also bind him to the tools chosen by the methodology and require some time to get familiar with the formalism. PERA and ASDI are open-architectures. They provide the outline, letting the user to choose the tools he wants to use.

PERA (Purdue Enterprise Reference Architecture) and the related Purdue methodology as developed at Purdue University as part of the work of the Industry-Purdue University Consortium for CIM (Williams 1994), is based on two classes of functions: the operating of the processes (manufacturing) and the processes involved in the control (information and control). PERA takes into account the full life cycle of the enterprise and emphasizes the need at the beginning of the process to define clearly the mission and the value of the company to control the execution of the process. Figure 10 illustrates the general outline of PERA methodology. However, PERA is designed for the enterprise life cycle and doesn't emphasize the knowledge acquisition through the process. We have so far not found any illustration of the application of PERA within the health care sector.

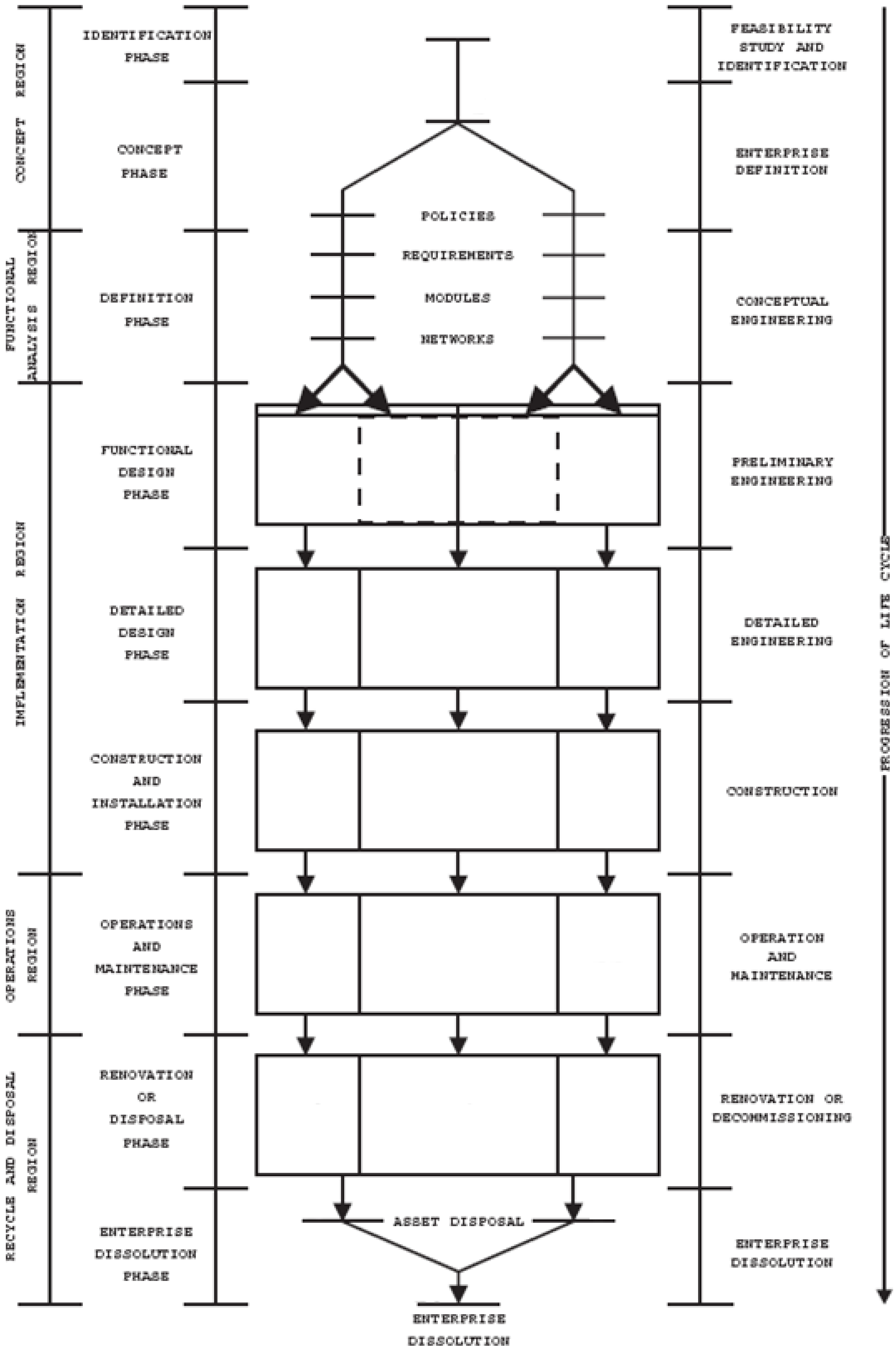

Figure 10. Overall form of the PERA architecture (Williams 1994)

ASDI (Analyse, Specification, Design, Implementation) methodology, developed by (Gourgand et al. 1991), is an open integrated environment of proven methods and tools helping in the gathering and documentation of knowledge to model and simulate production systems. The Figure 11 represents the architecture of this methodology. ASDI was used during the setup of a new hospital in France to model and simulate the health care supply chain and for the conception of an Advanced and Budgeting System (ABS) for that hospital (Chabrol et al. 2006; Fenies et al. 2005). ASDI methodology uses tools like ARIS and UML to define the processes.

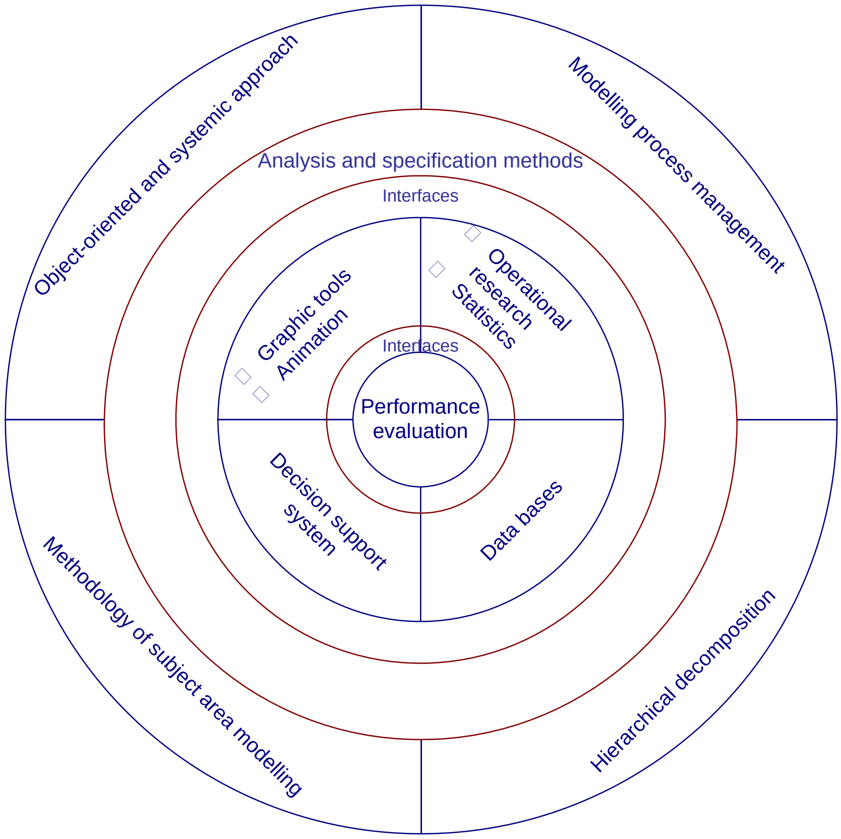

Figure 11. Software tools for the ASDI modeling

The methodology supposes that the values and the performance indicators are already clearly identified and the performance modeling is implicitly embedded in the analysis step, based on an Activity Based Costing methodology (Comelli et al. 2005).

To face the new changing environment, hospitals need tools and methodologies to identify, collect and organize the knowledge and to lead the changes. Numerous tools, techniques and software have been used so far. However, sole enterprise methodologies provide a full framework to describe the current situation and guide the user with the implementation of the proposed solution. The involvement of the personnel is very important in that kind of project. Within the health care sector the personnel has no time to learn complex methodologies and therefore the tools should be user-friendly, ease the communication and take little time to understand. It is why open architectures are best suitable, letting the user choose the tools he wants. PERA and ASDI are among the open architectures. PERA puts the emphasis on the mission, vision and value definition to define the performance indicators. The framework is however focused on the enterprise life cycle. ASDI emphasizes the knowledge building and its enrichment through the results analysis to better apprehend the behavior of the system. In addition, ASDI has been already successfully applied in the hospital.

2 *Hospital Information Systems (HIS)*

2.1 Context

A reengineering project relies heavily on the information available and has to be supported by information technologies and methods that accurately measure the performance of the system. Information processing for hospital is important for the decision makers. Almost all health care professionals need a vast amount of information. This information is a factor of (Haux et al. 2004):

- Quality: information is essential for the quality of patient care. When a patient is admitted to a hospital, a physician or a nurse needs information about the reasons for his admission and his medical history. Then, information about the results of medical examinations will be needed for medical diagnosis. The hospital administration and management also need information to carry the administrative tasks that support the care process (billing, ordering) and to control the hospital working in terms of costs and proceeds (Kaplan et al. 2007).
- Cost: due to the tremendous amount of information circulating in a hospital, the cost of information processing can be high. Investments in Information and Communication Technologies (ICT), in the forms of computer systems, computer networks, and computer-based application components, represent a non negligible part of a hospital budget. Information processing for health care is important and can lead to significant cost reduction; however, inefficient information processing leads to cost increase.
- Productivity: information needs to be available at the right time at the right place so that the health care practitioners can make sound decisions to improve the patient’s health; information can also help the economic management of the hospital to take the right decisions and have a control upon the hospital activities.
- Memory: the hospital information system also receives, transmits, processes, stores and present information. The quality of a hospital information system is essential to adequately recognize and store facts, to remember them and to act on them.
- Holistic view of the patient and of the hospital: the information system (IS) has to make the information about the patient completely available in every parts of the hospital. Due to the specialization of medicine and to the fragmentation of the information, it is important that the IS make the patient’s information completely available in every parts of the hospital so that the physician can take the best decisions about the treatment. The IS has also to provide the management with a

complete view of the hospital to monitor the care and medico-technical units and keep track of the activities.

2.2 Development of information systems within hospitals

Health care information systems have evolved, moving through several different phases of technology. There is also an evolution in the way hospitals conceptualize and manage information systems (Bourke 1994).

The informatics was first introduced in the hospital in the early 60's with the appearance of the IBM mainframe. The first application of computers was mostly patient-care oriented and not concerned with administrative functions. The goals were to improve patient care and productivity of the care givers. This expensive centralized technology was mainly used and developed in large hospitals. The spread of the microcomputers in the mid 70's provided a great opportunity towards a departmental control and less centralized applications. The information system had then to support financial operations such as charge capture and order entry. The early 80's was marked by a new emphasis on data bases that had more flexibility in screen and report design. At that time was introduced the personal computer and the first legislation to control health care costs based on activity levels (Diagnosis related group legislation in the USA). Prospective payments, in theory, forced hospitals to behave more competitively, requiring that they manage costs, products lines and markets. Applications developed previously needed thus to be integrated and the need for standard was coming to front. Some standards have been developed as HL7 (www.hl7.org) and MEDIX (www.medix.com) for example. The beginning of the 90's saw the starting of broad use of expert systems, voice recognition and electronic imaging. Hospitals were learning how to use the connectivity tools, encouraged by some factors as the US government announcement of intention to collect electronic data on quality of care, the increase in the connectivity of networks and multiple data bases and the growth of standards.

However, all hospitals have not deployed ICT so widely due to financial costs, time and organizational changes implied by the adoption of this technology. A wide variety of systems coexist in the health care sector.

2.3 Definition

An information system is (Haux et al. 2004) the socio-technical subsystem of a hospital which comprises all information processing as well as the associated human or technical actors in their respective processing roles. "Socio-" refers to the people involved in information processing as the physicians, nurses, administrative staffs, technical staffs and management. "Technical" refers to information processing tools that are used in that kind of system. The people and machines in a system are considered only in their role as information processors, carrying out specific actions following established rules.

An information system that comprises computer-based information processing and communication tools is called a computer-supported information system.

The objectives of this system are to enable the adequate execution of hospital functions for patient care, including patient administration, taking into account economic hospital management as well as legal and other requirements. According to (Winter et al. 2001), this system has to give:

- "Information, primarily about patients, in a way that it is correct, pertinent and up to date, accessible to the right persons at the right location in a usable format. It must be correctly collected, stored, processes and documented;
- Knowledge, primarily about diseases, drugs actions and adverse effects-to support diagnosis and therapy;
- Information about the quality of patient care and about hospital performance and costs".

2.4 Types of hospital information system

As we underlined it, there is a multiplicity of hospital information system and they can be classified based on the different functions that they fill in (Fabbes-Costes et al. 2003).

2.4.1 HIS in the domain of care

HIS in the domain of care have been developed to help the medical personnel with the care practices. These systems stored two types of data (Magne et al. 1989): the data about the patient, giving general information about the patient, his medical history and the different elements of the patient file; and data about the care practices as medical protocols and help in prescription. The objectives are to help in the medical diagnosis, nurse diagnosis and the therapeutic and care activities; it helps to evaluate the effects of therapies and cares provided and to recommend the patient to the structure that can provide him with the best care.

Numerous software's have been developed to give an answer to some specific needs of the care providers as the evaluation of drugs effect on the patients or the effect of some therapies (Morice et al. 1994; Venot et al. 1989). These computer applications are based on expert systems (Brasil et al. 2001; Lavril et al. 1989), knowledge-based systems (Kalogeropoulos et al. 2003) or intelligent systems (Kokol et al. 2001).

However, the care treatments become more and more specialized. A patient is treated by different medical departments, which raises the question of the integration of these tools to provide a complete view of the patient's stay. The integration of the different systems, often based on different technologies, ask for more standardization in their conception and in the data that are recorded. Even if each medical specialty claims specificities and the need for its own designed solutions, a study lead by Magne (Magne et al. 1989) about the requirements of different units in terms of software concludes that the needs are indeed very similar.

2.4.2 HIS to manage the hospital

The measures taken by the funding Governments in America or in Europe to control costs and the quality of care forced hospitals to adopt information systems to meet the requirements in terms of billing and activity evaluation. In order to monitor the day-to-day operations, a number of application were developed "in-house" to answer some specific problems as the management of intensive care units and operating rooms and the management of nurses timetabling. However, these administration tools, based on separate applications, don't provide a good answer to the complexity of the health care system. As their care counterparts, management tools have to provide a general view of the patient's stay. Integrated tools have so been developed as DIOGENE (Borst et al. 1999). This tool is focused on data collection for administrative purpose and is linked with ARCHIMEDE, which provides care decision-aids (Breant et al. 2000).

To get more integration and since both information systems share data, more integrated software's have been developed as HELP (Gardner et al. 1999) and BICS (Teich et al. 1999) in the USA or HISCOM (Bakker et al. 1999) in the Netherlands. All these applications started from a care application in a specific department and have evolved progressively to include all the departments of the hospital. It took more than 20 years to these applications to come to maturity. These tools have been showed to be successful to improve the management and the care practices in the hospitals where they had been implemented but have not been so easily applied in other hospitals. Indeed, they have been developed for a specific hospital, taking into account its specific organizational framework. The adaptation to another health care institution takes time and generates high costs.

2.4.3 HIS to evaluate the hospital practices

To ensure the quality of the health care system, hospitals have been forced by the Governments to evaluate their practices. In order to achieve it, they have to provide the regulating bodies with information about the care dispensing. These data include most of the time demographics characteristics, diagnoses of patients and codes for procedure.

In France, hospitals have to gather data to describe the activity for in and out patients due to the adoption by the State of a DRG-inspired hospital management system, the T2A. The gathering of these data, the "Plan de Médicalisation des Systems d'Information" gives also a basis for the accreditation of hospitals. In the USA, this was started with the Medicaid system.

At the beginning, there were high hopes in the evaluation of the administrative data. However, the accuracy of these data to evaluate the practices is not proven. According to the Agency for Health Care Policy and Research (AHCPR), "administrative databases generally have not proved useful in answering questions about the comparative effectiveness of alternative medical treatments". Indeed, with some exceptions, administrative data allow limited insight into the quality of processes of care, errors of omission and the appropriateness of care (Iezzoni 1997).

2.5 Some challenges

The introduction of innovation into an organization will evoke changes. In some cases, these changes will be minor ones that hardly affect the organization and the people working in it. In other cases, those having to use the innovation might experience major changes. Among health care professionals, new innovations are predominantly judged by their direct value for patient care.

One of the challenges in using the HIS is in terms of accuracy of the data, on which relies heavily the decision-aids software. The data are accurate if they are complete and correct.

The completeness refers to the proportion of observations that are actually recorded in the system, and the correctness, to the proportion of recorded observations in the system that are correct. According to the study led by Hogan et al. (Hogan et al. 1997), few studies have been so far done to evaluate the accuracy of data in the system; based on the literature review of different applications, they could evaluate the data accuracy around 80% of data stored in the systems. The main source of problems for data accuracy is data entry. The way the information system is designed can influence it. To ease the process of data entry, built-in reports and controls can be used to have the complete information. One has however to be thought careful with the use of these tools: if they are too rigid, users may want to put the information in the open box, using them inappropriately (Berg 2001). To ensure the correctness of the data, the personnel have to be implied in the development of the solutions. To have complete data, some solutions as the capture as automatically as possible of the information using bar code or RFID can be considered but these technologies are still today expensive.

Another main challenge in health care is the security of the data. Due to the sensitivity of personal and medical data, the development of integrated information system in a first time and of the care network in a second time raises the questions about the data protection, the authentification of the different actors, the management of the access right. Design technics and standards have been developed to ensure that the data are provided in a trustworthy way (Blobel 2000; Blobel 2007; Blobel et al. 2001).

Another challenge is how to assess the HIS. Most of the software's are evaluated based on selected outcomes as technical and economic factors at the expenses of social, cultural, political or work life issue. The use of these tools is thought to have the potential to improve care or at least to change physician's behaviors (Kaplan 2001). Their evaluation should thus be based on the system accuracy and on how well the physicians perform when actually using these systems.

3 *Supply chain*

As we mentioned it in the introduction chapter, health care supply chain has been receiving a lot of attention from OR researchers. Improving the quality of services by considering limited resources is a major challenge. Across the supply chain, different problems have been tackled and we organized them according the three stages of the supply chain:

- Procurement and inventory management
- Production of care in the sense of the management and planning of resources directly involved in the patient's treatment
- Distribution

3.1 Procurement and inventory management

Traditional inventory management methods for hospitals are based on a replenishment level. The supply distribution systems widely used are the cart exchange systems or the ROP/EOQ[2] model, called PAR level (Prashant 1991; Taylor 1990). These systems have been widely applied because they are easy to set up, do not require sophisticated information systems and have led to reduce the amount of stocks (anonymous 1998). However, a major issue in setting PAR levels for various items is that these levels tend to reflect the desired inventory levels of patient care givers rather than the actual inventory levels needed in a department. In most cases, these PAR levels are indeed constrained by the space available, are experience-based or are politically driven which lead to over-stocking for some items while other items should be ordered on non replenishment day (Rackoff et al. 1985). Different models have been developed to settle on the level of replenishment, based on historical data.

To determine the quantity and frequency of replenishment, derived EOQ formulas have been applied. Because of the lack of information systems, simple models based on a deterministic pattern using the average demand for a specified time period have been used (Burns et al. 2001; Hassan et al. 2005). The use of steady-state inventory models to determine inventory levels are however not appropriate for many items because the demand is non stationary. The materials planning decision models must consider non-stationary demand processes explicitly. Otherwise, excessive stock will be created.

The demand uncertainty makes it more difficult to control the system. The less precise the control is the more inventories are needed to serve customer adequately. In the health care sector, a product cannot run out of stock because it can affect the patient's life. Dellaert et al. (Dellaert et al. 1996) and Nicholson et al. (Nicholson et al. 2004) propose models with stochastic demand and service level to tackle this problem.

Dellaert et al. (Dellaert et al. 1996) consider a patient arrival time following a Poisson distribution and transactions sizes that are normally distributed. They propose a (R,s,c,S)[3] model for a multi-item, one stage, one period problem where the parameters s, c, S are determined in a very intuitive way, derived from the EOQ formula. They compare the performance of this rule to a two-step method based on Markov chain and proposed by Federgruen et al. (Ferdergruen et al. 1984). The performance in terms of costs is comparable but the model is quicker to compute. Nicholson et al. (Nicholson et al. 2004) were interested in a one-item, single period, multi-stage problem. The introduction of service levels constraints in a multi-stage environment makes the problem NP-hard because it has a non linear objective function with a set of non convex constraints. The authors propose a greedy heuristic exploiting the newsboy structure of the problem to solve it.

The models based on the EOQ replenish the inventory stock based on the past demand in order to satisfy the future demand. The specific safety stock level established will be a function of the degree of demand volatility, thereby necessitating further investment. These models assume that the future demand for each item is uncertain and independent.

[2] Reorder point policy based on the economical order quantity

[3] R stands for review period, s for the order level, c is the can order level and S is the order-up-to level

However, as a part of the activity can be plan, some authors discuss the application of the MRPII concept to support the scheduling and the inventory control (Roth et al. 1995; Showalter 1987; van Merode et al. 2004).

Roth et al. (Roth et al. 1995) develop a hospital based planning and control system called Hospital Resources Planning (HRP). They use the concept of the DRG (diagnosis related group) as a bill of resources to estimate the consumption of materials. The DRG is a patient classification system based on similar materials and resource requirements. Independent variables for sorting the DRG include surgical procedures or the joint combination of surgical procedure and range of patient ages. Patients within a same DRG are clinically similar. Treatment of patients within a DRG requires the same bill of resources (BOR).

Applying this concept, Rossi et al. (Rossi-Turck et al. 2004) test the use of standard kits and standard preference lists associated with surgical procedures in the operating theatre. This resource management method has led to decrease the amount of sterile materials inventory while maintaining a good service level.

Applying MRP systems gives the quantities needed according to the future demand but doesn't give an answer to inventory management question: how much supply? When? And what is the safety stock level? In addition, the implementation of the MRP concept in the hospital has shortcomings (Roth et al. 1995), especially in an emergency room (ER). Hospital activity is not 100% predictable and is highly variable. In particular, the emergency rooms activity has to deal with two majors uncertainties. The demand is highly uncertain and the number of DRG (Diagnosis Related Group) is therefore not known in advance. The number of items from the preference list consumed can also vary from one DRG to another. This phenomenon is even accentuated in the ER where even the diagnostic is not always easily set. The bill of resources is stochastic. To deal with that kind of problem within a hospital, different approaches were proposed, each leading to unsatisfactory performance. To reduce this variability, Roth et al. (Roth and Van Dierdonck, 1995) suggest using the average consumption within each historical data within the hospital. However, the use of mean consumption had showed to be counterproductive in such environment (Harper, 2002). van Merode et al. (van Merode et al., 2004) suggest to treat separately deterministic and non deterministic processes. They propose to treat deterministic processes with ERP while using an Advanced Planning and Scheduling software (APS) to manage reactively the stochastic processes on a day-to-day basis, as the emergency admission.

The use of the MRP concept in an uncertain environment has been widely studied in the manufacturing context and different methods have been proposed to face the different kind of uncertainties (Koh et al., 2002). When uncertainties come from the demand, the best performing rules are lot-sizing rules and the use of safety stock (Brennan and Gupta, 1993) (Caridi and Cigolini, 2002).

Just-In-Time concepts were also applied in a hospital. While the concept of JIT is applicable to the health care institutions (Jarett, 1998), the costs of implementation make it worth only for the high volume or value products. There are also organizational benefits through the standardization of the different products used and with a better linkage with the suppliers (Rivard-Royer et al., 2002). Epstein (Epstein, 2000) studied the opportunity of linking the OR scheduling information system to the materials management system for applying just-in-time inventory management. They considered deterministic patterns, with all surgeries and materials consumption known. The setup costs and the need for safety stocks make the system valuable for expensive or high-volume consumption products.

3.2 Management and planning of health care resources

As Governments in industrialized countries lead policy to facilitate access to care, demand for health care services exceeds the supply. In most of these countries, public funded health systems imply a cash-limited system. The most scarce and expensive resources as the nurses, beds, operating rooms and diagnostic services are therefore under scrutiny. Researchers focus on their best allocation and management to obtain the best outcomes possible with the funds available. The research themes are the sizing, planning and scheduling of these assets (Di Martinelly et al. 2004).

3.2.1 Resources allocation and management rules

The resource allocation problems deal with the allotment of the appropriate number of resources (beds, nurses, operating theatre) to a medical specialty to face a certain level of activity. The evaluation of the needed quantity is important because once defined, they will act as a constraint that is not readily relaxed. An over-capacity leads to additional cost for material assets and personnel and non profitable investment while an under-capacity results in delay in patient hospitalization, lower quality of care, etc. The objective is to find the right number of resources to balance the occupancy rate of the resource and the demand for that resource. So far, most of the researches have been focused on the problem of beds allocation to a specialty. Both mathematical models and simulation have been used to solve the capacity allotment problem. Mathematical models describe the system using variables and constraints to find the assignment of resources that minimizes the costs. Simulation offers more flexibility and makes it possible to consider more aspects of the problem.

Vissers (Vissers 1998) proposes an approach in 3 steps based on a linear program to allocate the resources to a care unit.

1. Identification of the bottleneck resource amongst the beds, the nurses or the operating rooms using the occupancy rate realized.
2. Allocation of the bottleneck resource to specialties based on the actual demand for that resource (using the linear program).
3. Allocation of the other resources to the department based on the allotment of the bottleneck and based on the constraints linking the resources. These allocations are made using a load target of 90%.

This method was tested in the context of a Dutch hospital with a target load of 90% concerning the bed occupancy and led to satisfying results. The author chooses this target that is an average to face the variation over the period and the uncertainty inherent in the health care activity. This study relies on the estimated number of patients per day and on the estimated length of stay and was tested in care units where emergencies represent a small proportion of admissions.

Because of the time scale considered, the day, and of the shortening of the length of stay, an imbalance of resources can be triggered. Indeed, the patients are discharged the morning and new cases are admitted in the afternoon. A study led by Lapierre et al. (Lapierre et al. 1999) showed a discrepancy of up to 20% between the average census-at-midnight and the average census at some other time during the same day for the number of occupied beds. The timing should therefore be taken into account. Lapierre et al. (Lapierre et al. 1999) use a time series model with hourly census data to avoid an overestimation of the number of beds allotted to a care unit. In addition, this approach minimizes the data collection and modeling efforts.

This type of approach can have good results when the proportion of elective patients is high. In other departments as the emergency rooms or the intensive care units (ICU), the level of activity is highly uncertain due to the emergencies. The use of the simulation completes optimization studies through the building of 'what-if' analyses. It allows increasing the understanding and insight of the system working by varying parameters and observing the outcome. For instance, several authors (Kao et al. 1981; Ridge et al. 1998; Vassilacopoulos 1985) use the queuing theory to determine the number of beds. Based on the patient's arrival rate, they determine the number of beds needed for a given service level and acceptable waiting time. These studies are completed by a robustness study using the simulation to evaluate the variation of the results under different changes in the assumptions (arrival's rate and patient's length of stay). VanBerkel et al. (VanBerkel et al. 2007) use the simulation to understand the effect of the number of OR and number of beds available on the waiting times in a general surgery department. They show that the long waiting time are more dependent upon the number of beds available than OR time available. They emphasize the good management of the resources that are occupied for longer period.

The simulation is also used to develop decision aid tools. After determining the capacity, it allows for instance testing different admission policies (El-Darzi et al. 1998) for the elective patients. Huang (Huang 1998) uses the simulation combined with an optimization method to provide decision support in sizing a care unit taking into account emergencies admission. He tries to minimize the beds overflow. Kim et al. (Kim et al. 2000; Kim et al. 2002a) test different admission planning strategies to manage both planned and emergency patients in an intensive care unit. They develop a decision aid tool in a multi-objectives environment based on simulation to test several bed reservation policies for the elective patients. They demonstrate that the use of a flexible allocation scheme varying according to the day of the week allow having more free beds and allow better management of cancelled surgeries. In the second article, they test reservation bed schemes based on a quota for the elective patients and use a time window of 1 or 2 weeks. They show the importance of considering the impact of a decision made today on the coming admissions.

3.2.2 Planning and scheduling

Once the capacity has been defined, it is the constraining factor. Because the resources are expensive, i.e. the budget to build a new OR, or scarce, i.e. the recurrent problem of nurses' shortage, it is crucial to reduce slack capacity and waste and to manage more efficiently the flow of patients. The planning of the activities should allow keeping an acceptable service time for the elective patients. This planning is made difficult due to the variability in length of stay for the planned admissions and the uncertainty about the number of emergency patients and their stay. Most of the researches focus on the planning of the elective surgeries. The uncertainty is handled through the use of dedicated resources.

The majority of the articles focus on the operating theatre planning and scheduling because this medico-technical unit is considered as the most costly resource in the hospital, up to 9% of the total budget (Gordon et al. 1988) and as one of its main bottleneck. Researches in the optimal scheduling of surgical procedures are structured to maximize resource utilization (operating rooms, beds, physicians) subject to a set of constraints.

The researches first focus on scheduling the elective surgeries, looking for maximizing a profit function (or minimizing overtime) and/or maximizing capacity utilization. Gerchak et al. (Gerchak et al. 1996) present a stochastic dynamic programming model and determine the elective surgeries that may be performed each day depending on the procedures that have to be done that day.

Another approach is to solve the problem in two steps to determine the scheduling within the OR: a planning and a scheduling stage for the elective surgeries. The planning phase determines the surgeries to be performed in an operating room and the scheduling determines the order for the surgeries. Marcon et al. (Marcon et al. 2003) model the problem of allocating operations to operating rooms as a multiple knapsack problem while minimizing the difference of workload between rooms and minimizing the risk of no-show. They suppose the day of surgical procedures known. Guinet et al. (Guinet et al. 2003) heuristically solve the assignment problem of interventions to operating rooms with resources capacity constraints and a deadline date for the procedure. They use an extension of the Hungarian method (Kuhn 1955). They minimize a cost function defined on the opening duration of an operating room and the patient waiting time. For scheduling surgical procedures, Kharraja (Kharraja 2003) considers the operating and recovery rooms with each *k* beds and models them as *k* flowshops. Chaabane (Chaabane 2004) treats the operating and recovery rooms as a hybrid flowshop with recirculation. However, all these approaches don't take into account emergencies or consumables and consider the surgical time known.

Most recent researches try to take into account the variability of the length of stay for the patients to determine the daily planning of the surgical intervention. Belien et al. (Belien et al. 2007) consider the problem of building cyclic surgery schedule. They consider both a stochastic number of patients and a stochastic length of stay. They propose mixed integer programming models build on heuristics and metaheuristics to minimize the expected total bed shortage. Two types of constraints are taken into account: the demand, to ensure that each surgeon as a block time during each cycle, and the capacity. Hans et al. (Hans et al. 2006) test various constructive heuristics and local search methods to build what they call a "robust surgery planning". They consider that there are enough surgeons and enough nurses to do the proposed planning. They emphasize the importance to have extensive number of patients' records to lead statistical analysis. Santibanez et al. (Santibáñez et al. 2007) use a mixed integer programming with constraints on the pre- and post- surgery activities, on the OR availability and on the surgeons time to minimize the maximum daily bed utilization. Hammami et al. (Hammami et al. 2007) propose a two-step approach based on integer linear programs to build a robust operating planning. Firstly, they build surgeons block times considering 3 types of block time: dedicated to the surgeon, dedicated to a surgical specialty or generalized. Secondly, they allocate the elective surgeries to the block times, going from the most specific to the less one. The objective is to minimize the number of delayed surgeries and to be able to integrate emergencies without degrading the OR performance.

Kusters et al. (Kusters et al. 1996) focus on the admission planning and propose a decision support system based on statistical analysis and simulation to predict the resource utilization of beds, nursing staff and operating rooms while optimizing the availability of emergency services. They base their approach on the assumption that a classification of patients can be done based on similar resources consumption.

3.2.3 Distribution

Distribution problem aims at determining the type of carriers and their number, the organization of the routes, the working schedules of the carriers.

Banerja et al. (Banerja-Brodeur et al. 1998) study linen distribution, to determine over the week, the itinerary and the frequency of linen delivery to the care units under constraints of size of cart and total linen available. The problem is modeled as the PVRP (Periodic Vehicule Routing Problem). The personnel constraints are not taken into account and the planning has to be modified to smooth the load over the period.

Gascon et al. (Gascon et al. 1997) propose a heuristic method to determine the working schedule of the carriers. Based on the different tasks to achieve, they determine the units to stop by and the timing and they evaluate the solution on multiples objectives. They take into account only the length of the task and don’t take into account the capacity available for each round.

Rossetti et al. (Rossetti et al. 2001) lead a comparison study between the use of automated guided vehicles or human-based delivery system to distribute pharmaceuticals products and clinical analysis. They use a decision-aid methodology based on simulation to evaluate the best alternative. In a first time, they use the Analytic Hierarchical Process to define and rank performance indicators related to the distribution process. The simulation provides value for the performance indicators and is used to analyze the robustness to verify the stability of the solution when decision maker preferences vary. The authors underline the importance of the referential for performance indicators.

3.3 Integrated health care supply chain

Even if several authors underline the benefits of integrating the hospital supply chain (Aptel et al. 2001; Brennan 1998; van Merode et al. 2004) there are still a few studies that apply the approach in hospital.

Ruiz (Ruiz Bartolomé 2002) proposes a multi-period mathematical model. The objective function maximizes a non utility function and integrates nurses scheduling management. He seeks to smooth the workload and minimizes backorder costs. The solution is obtained by a tabou heuristic under the assumption of a deterministic demand.

3.4 Classification

The researches we summarized have been ranked based on the types of decisions levels as shown in the Table 3.

The strategic decisions give the long term orientation of the hospital and are related to the stable resources needed to reach the objectives. The resources considered are the machines and materials, people and the information. Considering the supply chain, the decisions to be taken are:

- The type of inventory management system to set up.
- The investment in stable resources to have the capacity to meet the demand and the objectives.
- The type of distribution system to use.

Table 3. Classification of the researches

Decision level	*Inventory and distribution*	*Production of care*
Strategic	(Taylor 1990) (Prashant 1991) (Roth et al. 1995) (van Merode et al. 2004) (Rivard-Royer et al. 2002) (Epstein 2000) (Rossetti et al. 2001)	(Vissers 1998) (Lapierre et al. 1999) (Kao et al. 1981) (Ridge et al. 1998) (Vassilacopoulos 1985) (VanBerkel et al. 2007) (El-Darzi et al. 1998) (Huang 1998) (Kim et al. 2000; Kim et al. 2002a)
Tactical	(Rossi-Turck et al. 2004) (Gascon et al. 1997)	(Gerchak et al. 1996) (Marcon et al. 2003) (Guinet et al. 2003) (Belien et al. 2007) (Hammami et al. 2007) (Hans et al. 2006) (Santibáñez et al. 2007) (Vissers 1998)
Operational	(Hassan et al. 2005) (Burns et al. 2001) (Nicholson et al. 2004) (Dellaert et al. 1996) (Banerja-Brodeur et al. 1998)	(Kharraja 2003) (Chaabane 2004)

Strategic decisions should help the hospital to reach its goals. However, in most papers we have found so far, the main objective is the cost reduction. The researches done about inventory management consider through case studies the opportunity to put in place another inventory management system to reduce the quantities in stock. The papers about the sizing focus on the determination of the right number of resources to meet occupancy level targets to ultimately minimize the costs. These resources are directly implied in a complex activity, the patient’s care. To better apprehend it, most authors use the simulation either in combination with an optimization method either as a decision tool. In the first case, it allows testing how the system responds to different changes in assumptions. In the latter, the decision maker is provided with measures of the system performance. However, in both cases, there is no information on how these indicators have been chosen. Only the study led by Rossetti et al. (Rossetti et al. 2001) show the importance of the performance indicators definition but take into account only the point of view of the decision maker. This can lead to bias in the decisions since several studies underline the complexity to take decisions in health care because of the different stakeholders involved with conflicting objectives.

The decisions taken at the strategic level become a constraint at the tactical level. The resources planning and the transportation plan are established taking into account a certain capacity to meet the demand. The decisions are affected by a double uncertainty: the demand for the resources is uncertain and even if the demand is known, the consumption may vary. The latter is referred by (Roth et al. 1995) as the stochastic bill of resources. Some of the papers dealing with the management of the resources make a strong assumption considering the demand as deterministic. Another group of researches deals with the uncertainty using dedicated resources. In that case, the use of steady-state assumptions overestimates the need in capacity. The flexible allocation of these resources tends to lead to better results because the health care activity varies over the time. In addition, the greater the uncertainty is, the more safety resources are needed. One good policy is thus to reduce it as much as possible using for instance the standardization, as in the approach proposed by Rossi et al. (Rossi-Turck et al. 2004) to manage sterile materials within the OR.

The decisions at the operational level concern the daily flexibility of activities to deal with the demand and resources available. The decisions are related to the inventory management and the scheduling to have a detailed programming of the resources used. In terms of inventory management, the models proposed so far make restrictive assumptions about the system described. Indeed, the stochastic demand and the service level make the problem difficult to solve and few computational approaches have been proposed and applied in the health care. The OR scheduling approaches are based on a decomposition method, starting from an allocation of the patients to the different rooms. However, this kind of approach doesn’t take into account the interactions between the planning and the scheduling phases. Even if there are enough resources to meet globally the demand, it may lead to an infeasible schedule (Beliën et al. 2006).

Chapter 3. Value modeling and performance definition

1 *Research project*

As we explained it in the first chapter, the motivation of our research is the collaboration with a Belgian hospital that reorganizes its supply chain activities. The building of the new logistical platform will impact the products flow, the distribution and the inventory management. Numerous people, products and care units will therefore be concerned by this project. Before implementing changes in a complex system, it's needed to understand its working to identify what are the interactions between the different elements and to have a proper diagnosis of the weaknesses. Modeling methodologies are a good support to identify problems and to propose solutions. The literature review we made about these methods helps us to choose the ASDI methodology. This open architecture will also ease the communication and has already been successfully applied in hospitals. The ASDI framework considers that the value modeling is already stated and that the system is mainly evaluated on financial indicators. However, we share the same point of view than the authors of PERA who estimate that the value and performance modeling is not obvious and need specific attention. As Porter underlined it (Porter et al. 2004), the evaluation of the health care systems, only based on financial indicators, leads to poor performance. The literature review on the health care supply chain researches shows us that all strategic decisions were guided by financial indicators. Only the standpoint of the management is taken into account even if multiple stakeholders are involved in the hospital activity.

In such a context, we propose to develop an approach to reengineer and evaluate the hospital supply chain using an adapted value modeling and performance definition. The approach should help the hospital managers to reorganize their supply chain, mainly the medical products supply chain, while taking into account the patients' flow.

1.1 Suggested methodology

We suggest a framework that provides guidance to build a knowledge model based on the ASDI methodology and enriched with the value modeling and performance definition. The knowledge model is aimed at understanding the working of the system, identifying the critical activities, defining the performance indicators to assess the system based on metrics in accordance with the value system, describing processes and management rules and identifying resources.

The ASDI architecture (Analysis-Specification-Design-Implementation), developed by (Gourgand et al. 1991) consists in four steps. The Figure 12 depicts the different phases of this approach, but we already integrate the value and performance model (Di Martinelly et al. 2007b).

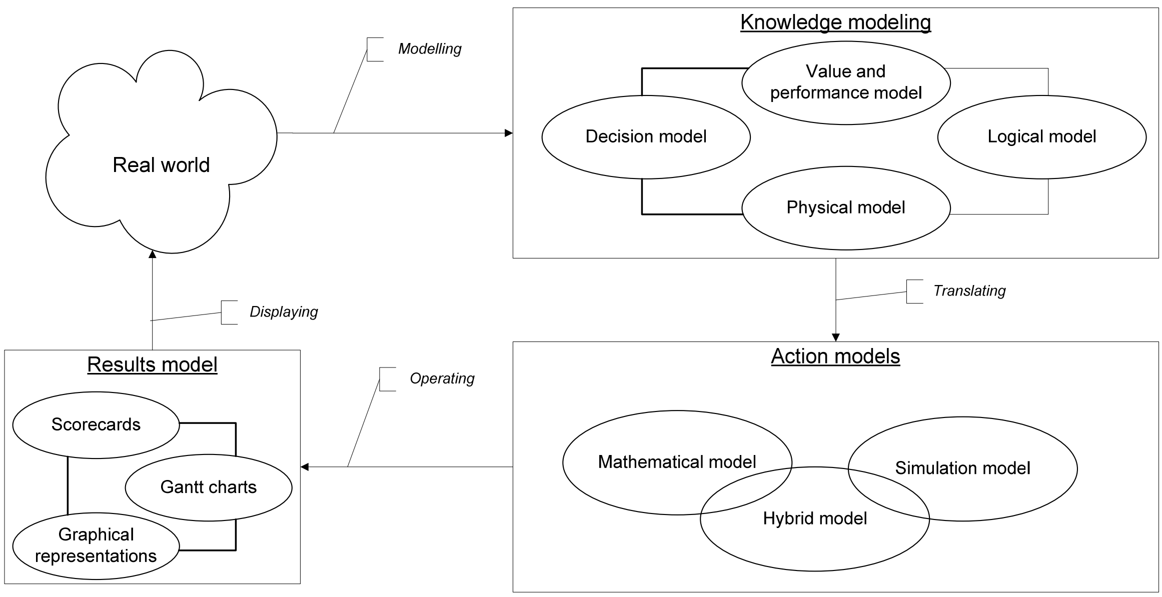

Figure 12. Adapted and enhanced ASDI Methodology

- Modeling the system: this step deals with the study, the analysis of the system, the identification of its physical structure and information exchanges, the processes documentation, the specification of its decisional procedures, the objectives translation and the performance indicators definitions. This step allows us to acquire the necessary knowledge to make a diagnostic of the system weaknesses and to propose solutions.
- Translating the models: this step consists in deriving as automatically as possible the appropriate actions models (optimization and simulation programs) directly from the knowledge modeling established before. The action models replicate the working of the system and serve to evaluate the impact of the different strategies before implementation.

- Operating the models: the action models are used to validate solutions and evaluate the appropriate scenarios on the basis of performance indicators defined according to the established value model.
- Displaying the results: Once the analysis of the results confirms the pertinence of the proposed solutions and upholds the improvement of the current system, based on the scorecards, Gantt charts and graphics, its deployment can be possible.

The central point of our extension to the ASDI methodology concerns the value and performance modeling. The performance analysis in the original method is based on an activity based costing methodology, assuming that the system should be evaluated only on financial criteria (Comelli et al. 2006). This type of pricing system is suitable to assess systems in the merchant sector. A study led by (Eldenburg et al. 1997) tends to prove that a finance-based system is appropriate to monitor the hospital performance against the actual care activity. However, it supposes that a cost model is sufficient to gauge the performance of a hospital. This assumption was proven to lead to unsatisfactory quality performance with regard to patients and hospital personnel expectations (Porter et al. 2004).

We thus expand the knowledge modeling by suggesting a way of constructing such a value and performance model that better takes into account the stakeholders' expectations. The knowledge modeling consists now in establishing four sub-models:

- The physical model describes physical entities and resources that are part of the transformation of activities and that create value. The different elements are represented through resources maps, and physical layout.
- The logical model describes the processes we focus on, details exchanged information and operating rules. The different processes are identified and detailed through questionnaires and interviews of the different actors; they are represented by logical diagrams; the tools used can be ARIS, SADT, etc. .
- The decision model defines the working and control rules of the system. The decisions might be identified and structured using the GRAI grid.
- The value and performance model has first to clarify the statement of the strategy and the value the hospital wants to promote, to identify the activities that create value for care and define the performance indicators consistent with the objectives inferred from the hospital strategy. These indicators will help to monitor efficiently the system. The value and performance model will be elaborated based on the Porter's models and the balanced scorecard framework. The Figure 13 illustrates the different steps to build the value and performance model. The different tools used are embedded in an oval shape. These steps will be developed in the next point.

This approach of knowledge modeling provides the user an understanding of the hospital elements and helps in identifying the weaknesses. This allows to diagnose the system working and to propose improvement solutions. The action models replicate the system working and evaluate, before their implementation, the proposed solutions on basis of the performance indicators defined during the knowledge modeling. This methodology will ensure that the suggested changes improve the working of the pharmaceuticals supply chain and contribute to the global interest of the hospital.

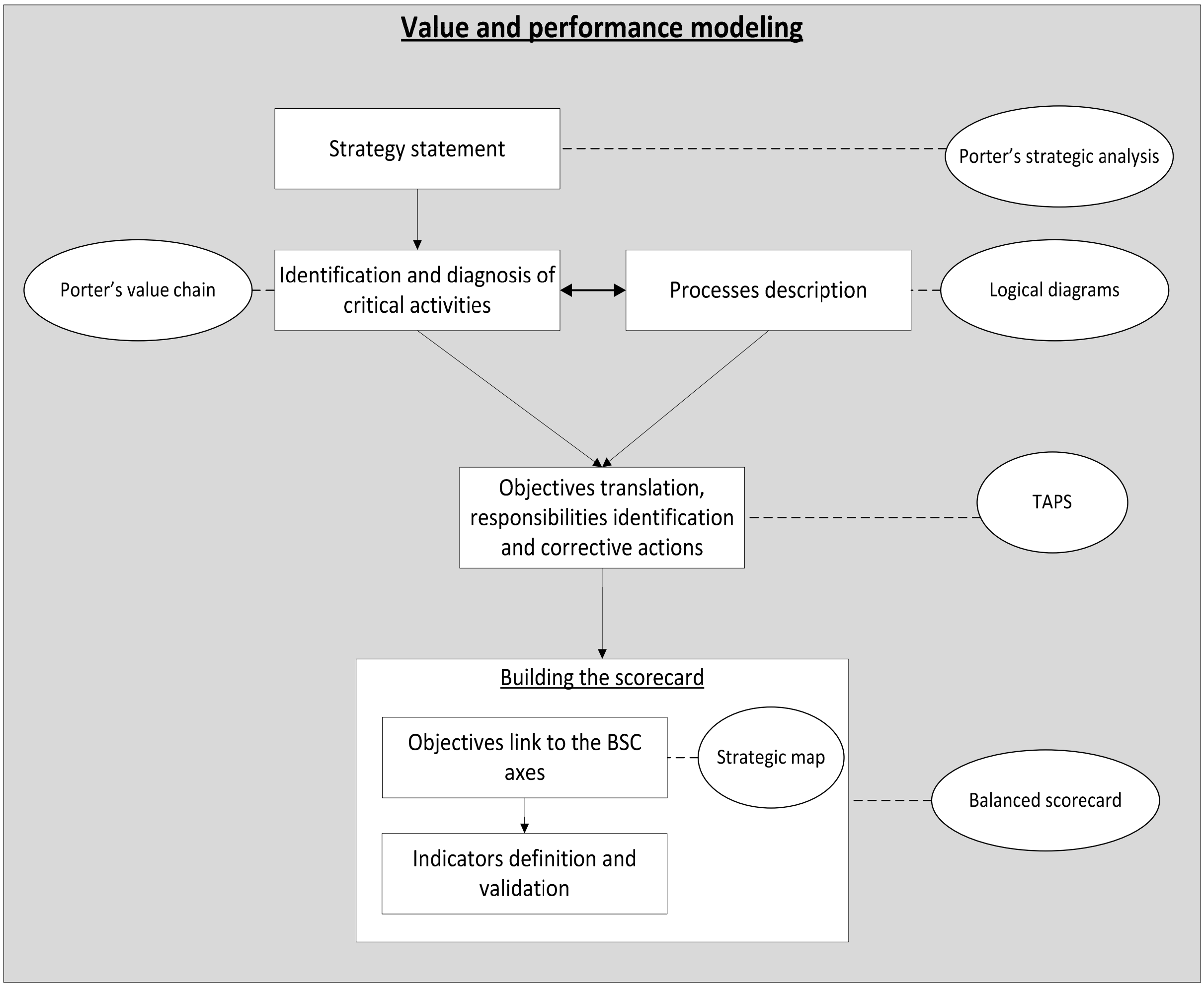

Figure 13. Approach for the value and performance modeling

2 *Value and performance modeling*

In this part, we detail the construction of the value and performance model which is the core of our extension to the ASDI methodology. We propose a five-step approach, depicted in the Figure 13, to define the indicators: the statement of the strategy, the identification of the critical activities, the processes description, the objectives translation and the indicators building and scorecard establishment. The use of this framework should ensure that the defined performance indicators appropriately assess the proposed solutions against the strategy and value of the hospital.

2.1 Strategy statement

For most companies, the statement of a strategy is the most important decision because it gives the direction to follow. It determines the scope of the objectives and sets the outline of the actions to undertake to achieve them. Though, the translation of the strategy into objectives at the different decisions level is a difficult exercise. As underlined by some authors (MacStravic 1999; Weber 2001), the performance definition in the health care sector is not obvious because of the different value perceptions of the four constituents that generate revenue for the hospitals, i.e., the payers, the patients, the regulators and the physicians. This makes the statement of the strategy and the value more complex to set compared to other industries. Different strategic management models have been developed to help the executives of a company to create and defend effectively a firm's competitive position, as the 7-S Framework from McKinsey (Waterman 1982), the Fine & Hax methodology (Fine et al. 1985) and the Porter’s strategic analysis (Porter 1985).

The 7-S Framework from McKinsey (Waterman 1982) is a tool for the formulation and implementation of a doable strategy, focusing on the internal working of the company. The Fine & Hax methodology (Fine et al. 1985) was developed in a first time for manufacturing companies to help them with the definition of the strategy. It addresses the interrelationships between the firm’s operation units, its other functions, its competitors and the markets. The Porter’s strategic analysis (Porter 1985), also named competitive analysis, studies the industry in which compete a firm to define its attractiveness and the right strategy to adopt to get a competitive advantage. He identifies 4 main strategies that could be adopted to have a profitable and sustainable position against the forces that determine the industry competition. There are two basic types of competitive advantage a firm can possess: low cost or differentiation. The two basic types of competitive advantage combined with the scope of activities for which a firm seeks to achieve them, lead to three generic strategies for achieving above average performance in an industry: cost leadership, differentiation, and focus. The focus strategy has two variants, cost focus and differentiation focus. The Figure 14 schematizes these different strategies.

Some of these models have been applied to the health care sector since there is no specific model of strategic planning which addresses the divergence that exists in the industry of health care (Swinehart et al. 1995).

Swinehart (Swinehart et al. 1995) adapted the Fine & Hax methodology to the health care sector but did not implement it. This framework gives in addition little insight into how the environment and the regulatory aspects have an impact on the strategy and on the different forces that make it achievable. The Porter’s model has been successfully applied to the health care sector to define the mission statement at a strategic level (Porter et al. 2004) or to help in the choice of an information system at a tactical level (Osborn et al. 1989; Rackoff et al. 1985).

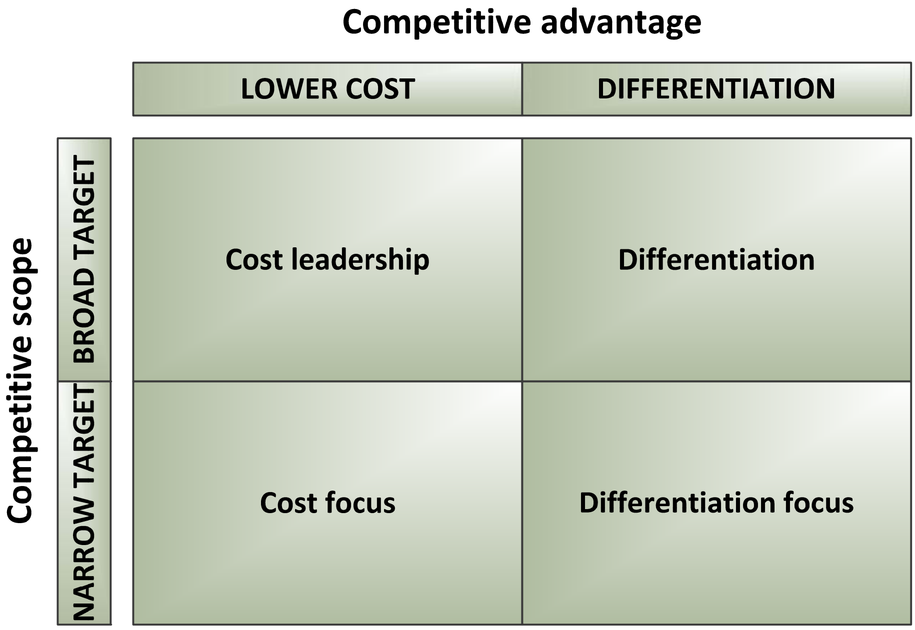

Figure 14. Porter's competitive strategies matrix

We thus apply the Porter's models to our problematic: the strategic or competitive analysis and the value chain analysis. The competitive analysis is a tool to determine whether an industry or a specific segment of a broader industry is attractive and to help with the choice of the type of strategy to follow. This analysis is made by studying the different competitive forces affecting the market. We lead this analysis for a specific segment of the health care industry, the hospital, and we were inspired by the research led by (Blair et al. 1998). In the strategic analysis conducted by Porter, the influence of the regulator that affects the different forces is implicitly taken into account since he considers that the market forces regulate the industry. However, in the health care industry, the regulator is considered as one of the main stakeholders (MacStravic 1999; Weber 2001). We underlined in the first chapter that, either in the USA or in Europe, the regulating bodies influence the way hospitals are organizing their logistical administration. We therefore add it as a sixth competitive force, affecting all the other stakeholders. The Figure 15 illustrates the difference forces that influence the definition of the strategy in the segment industry of the hospital.

- The suppliers. The main suppliers of hospitals are the physicians who refer patients to hospitals. From the logistical point of view, the main providers are the pharmaceutical groups or specific distributors. They provide them with drugs, medical materials and hospital furniture.
- The buyers. The main buyers of the hospital are the patients. They have limited information on care partly because services are highly customized. In addition, they also choose a hospital because of the geographical proximity, or doctors' referral. There is also a new shift in the buying of care, where managed care organizations decide where the patients may be hospitalized.
- The substitutes. The substitutes for hospitals are other care networks that can be developed.

- The potential entrants. The potential entrants are new hospitals or the setup of new networks.
- The regulator. The regulatory aspects influence the behavior of the different stakeholders by putting legal limitations to their actions.
- The rivalry between hospitals and its intensity is determined by the influence of these different elements.

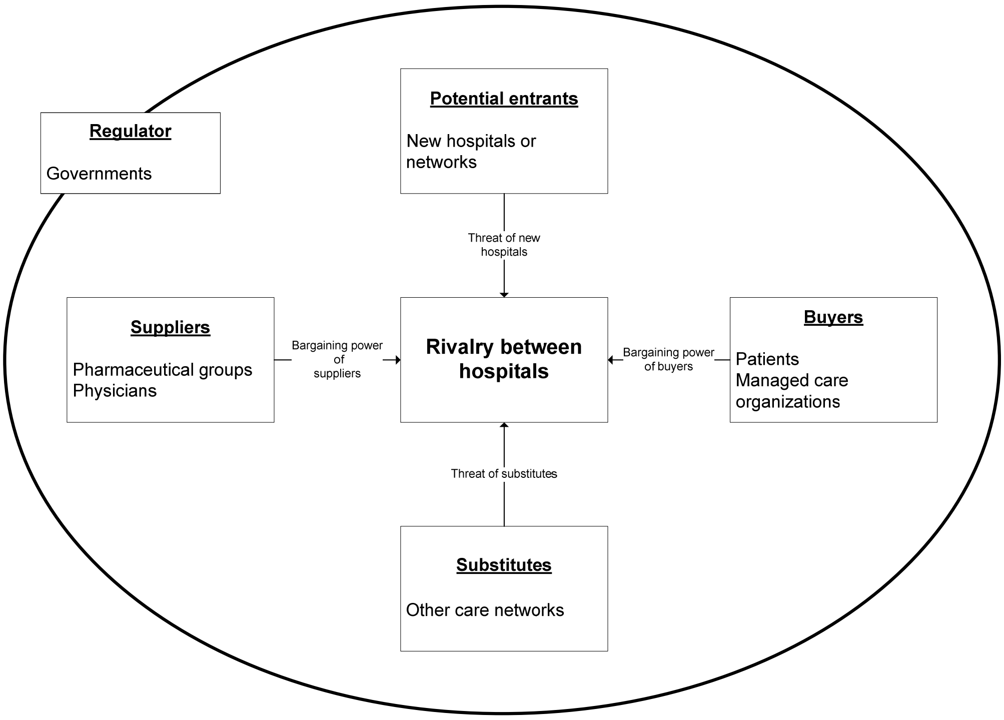

Figure 15. Porter's strategic analysis applied to the segment industry of hospital

As researches done by Langlois (Langlois et al. 1992) show it, firms providing a service such as hospitals can gain a competitive advantage by developing clients' relations and reducing costs. However, sole cost cutting objectives are not the solution on the long term. The American health system, largely private and subject to more competition than virtually any place in the world, has unsatisfactory costs and quality performance partly because of this wrong objective of expenses reduction (Porter et al. 2004). American hospitals indeed have focused on the services rationalization provided to the patients. The goal was to limit as much as possible the costs of the resources used to deliver the care. At the end however, few improvements in efficiency have been observed. As a result, the costs have been still rising but the service delivered to the patients was lowering.

The clients' relations are influenced by the perceived quality of care and prices. The performance of the system is measured by the efficiency and effectiveness of activities that use technical, human and financial resources to produce care of quality (Lebas 1995). The notion of "value" in the health care sector is thus composed of two elements: the quality of care for the patient and the economical value in the sense of productivity and competitiveness of the production system of care (Besombes et al. 2004). Therefore, whatever the strategy adopted by the hospital, they have to improve the quality of the care while maintaining costs under control.

The means used to apply the strategy is influenced by the structure of the industry. The general hospital context is rather different in the USA and in Europe. The Figure 16 illustrates a comparison between the relative strength of the different stakeholders between these two countries.

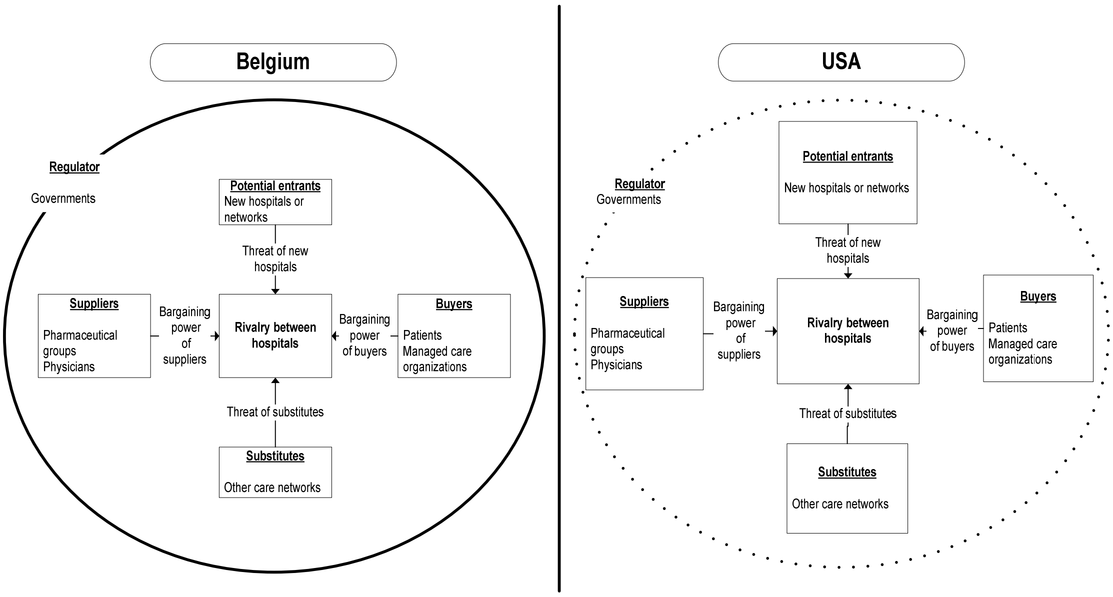

Figure 16**. Comparison between Belgium and USA**

- The suppliers. In both countries, the physicians refer the patients to hospitals and have therefore some lobbying power. If a physician is not satisfied with the quality of the service he receives from the health institution (OR not available on time or not enough nurses, unavailable pharmaceuticals ...) he might leave for another one, depriving the hospital from revenue. The pharmaceutical groups or distributors are the other main suppliers. They have an important bargaining power in the USA where the logistical supply is integrated: most hospitals have buying contracts with one main distributor (Aptel et al. 2001).
- The threat of new entrants or substitutes. In Belgium, the number of beds is ultimately regulated by the state through the funding of the health care institution. In the USA, hospitals are competing like private firms, limited by the economical reasoning.
- The power of the buyers. In the USA, managed care organizations, as insurance companies, set up contracts with specific health care networks and refers their patients to these particular institutions. The other buyers are patients. They have limited information on care partly because services are highly customized. The price may be a decision factor in the USA where the treatment price can greatly differ from one hospital to another. In Belgium, the care prices are in great part fixed by state.

The buyers' choice is mainly based on the quality perceived, their sensibility and the geographical proximity.

- The influence of the regulator is far less important in the USA where this sector is mainly private. In Belgium, the regulator intervenes to limit the number of beds, to define the rule of contracts award for suppliers and put pressure on hospitals to reduce the costs by subsidizing the patient's stay with a fixed amount of money, depending upon the diagnosis.

Due to the differences in the industry structures between the USA and Belgium, hospitals have operated their strategies in different ways. The American hospitals are competing in a rather similar environment than private companies and have more freedom to choose the variety of services they want to provide the patients with. To support the strategy they want to achieve, they put earlier the emphasis on the logistical function and have developed integrated supply chain concepts to provide materials and pharmaceuticals within the hospital (Aptel et al. 2001). As shown in the first chapter, they adopt a formally organized materials management department and they try to move as fast as possible the products from one part to another of the chain to reduce the costs. The application of just-in-time concepts in North America hospitals is a good example of that concept.

In Belgium and in France, the regulators earlier wanted to provide health services to each citizen, giving the hospitals the financial means to achieve this strategy. This politic led to an outnumbering of beds and a logistic function spread out between different departments to be as close as possible to the patients and to provide the best service possible. However, the accelerated technological developments in medicine equipments and management tools as the increasing demand for care resulting partially form the growing number of elderly people make this policy no more sustainable for the states. The Belgian and French governments now impose new financial targets to reduce the treatment costs of a disease and hospitals are considering solutions to reduce expenditure. Focusing on the logistical supply chain is thus a good way to reduce costs while improving the service level to the patients.

2.2 Identification and diagnosis of critical activities

Whatever the strategy chosen by the hospital, the strategic analysis proves that the focus on the supply chain is a good way for it to provide the patients with a care of quality while maintaining costs under control. Before going further, it is needed to understand how the logistical activities influence the main hospital activity, how these activities are intertwined and what are the activities that create value for the care. This will also help us to identify the key activities to analyze to focus our study.

The notion of value adding activities was used by Porter in his value chain analysis (Porter 1985). This model emphasizes the links between the different activities, identifies for each activity the costs and the value drivers in order to determine what the value adding activities are.

In the Figure 17, we apply the value model to emphasize the links between the main hospital activity (patient's care) and one of its support activities (the pharmaceuticals supply chain) and to estimate the impact of a pharmaceuticals process modification on the care process (Di Martinelly et al. 2006a). This analysis requires some knowledge of the system and is therefore led at the same time than the building of logical diagrams that will be described in the next point. The different activities identified through these diagrams are grouped according to the Porter's sub-categories.

The primary activities are dedicated to treat the patients and are divided into 5 sub-categories:

- Admission logistics: processes associated with patient's admission and management of their documents.
- Care dispensation: processes associated with care dispensing and their management.
- Discharge logistics: processes associated with patient's discharge, including follow-up treatment, rehabilitation.
- Finance: processes associated with the financial return of care: invoicing to patient and third party payers, information exchange with state-controlled organization, price setting activities.
- Service: processes associated with extra care activities and that can add value to care like volunteer services, social services.

The support processes hold up primary activities by providing human, technical and material resources. Among them, we identify:

- Hospital infrastructure: the organizational structure, the control system and the corporate culture.
- Human resource management: personal hiring, training and development, salaries.
- Technology development to support main activities: research and development, processes automation, computerization, etc. .
- Logistics: there are 6 main activities: one dedicated to the patient, the laundry, the waste management, the clinic pharmacy, the catering and the technical support (AS GHC, 2003).

The clinic pharmacy activities amount for the most part of hospital logistical activities. The objectives of the clinic pharmacy from a logistical point of view are to provide the patient with the right medicine, at the right time and in the right quantity, while providing them in condition that ensure security and traceability. We apply the Porter's model to the clinic pharmacy activities and end up with the five sub-categories:

- Inbound logistics: processes associated with pharmaceuticals purchase, reception and return.
- Production: processes associated with pharmaceuticals preparation.
- Outbound logistics: processes associated with the distribution throughout the hospital.

- Finance: processes associated with the pharmaceuticals price setting, reimbursement demand, etc. .
- Service: processes associated with pharmaceuticals testing, pharmaceuticals care.

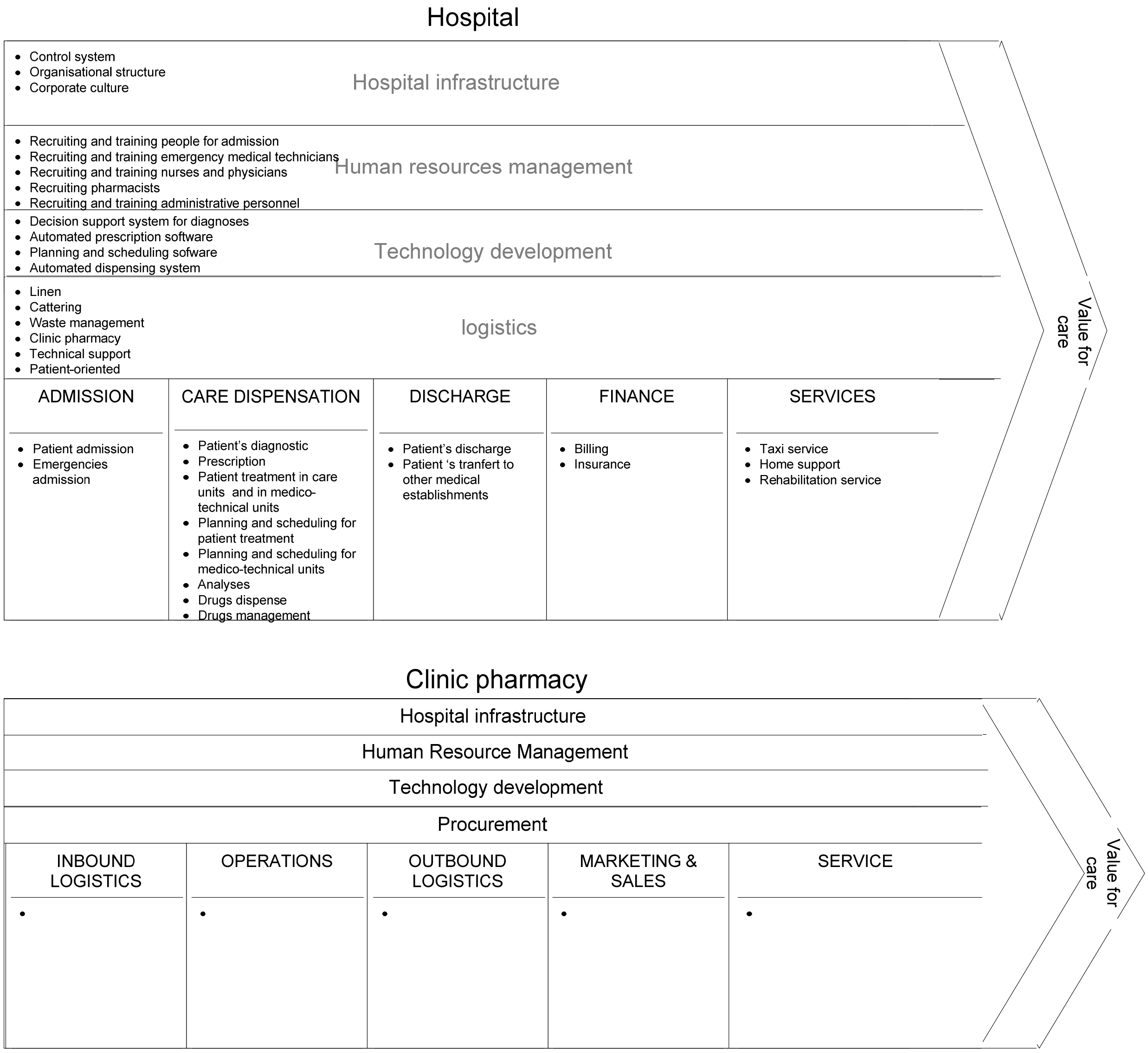

Figure 17. Porter's value chain applied to the hospital

The support processes of the clinic pharmacy activities are the same as those of the hospital. The information system has to support a perfect coordination between the patients' and the pharmaceutical flows to allow a proper dispensing, an adequate billing and the traceability of drugs.

Both of these value chains are highly intertwined. Their respective activities are linked. For instance:

- ‘Admission’ and ‘inbound logistics’: if the patients are known in advance, the pharmacy can already order the right amount of pharmaceuticals. It is particular useful for the prosthesis and the blood management.
- ‘Care dispensation’ and ‘outbound logistics’: all the pharmaceuticals have to be delivered on time and in the right quantity, otherwise the process is delayed; in some medico-technical units as the operating rooms, it is vital that all the materials and pharmaceuticals are available at the right time or else the intervention could be rescheduled.
- ‘Finance’ and ‘finance’: to provide the right billing to the patient, the general finance service has to know which pharmaceuticals were dispensed. It also ensures a better follow up of the pharmacy management.

The activities dealing with the patient’s treatment, the care dispensation activities, contribute a lot to the outcome of patient’s care. They are also intertwined with the clinic pharmacy activities as we’ve just shown it. Because of these links, any change in the supply chain may influence the costs and the performance of the main value chain and has to be carefully evaluated. However, so far, there is no idea of the current system performance and of what could be the potential benefits of a change. The Porter’s value chain doesn’t provide a tool to define a set of measures that reflects the objectives of the company and assess the performance appropriately, which requires measurement frameworks. In addition, the definition of the performance indicators requires a deep knowledge of the system. We therefore first describe the activities to have more insight into the working of the system.

2.3 Processes description

The Porter’s value chain model considers an activity-based theory of the firm (Porter 1985), where the activities are “the basic units of the competitive advantage, generating costs and creating value for buyers”. In his book, Porter views activities and processes as synonyms. We therefore use an approach based on the processes to describe the working of the hospital.

We consider a process as defined by the ISO standards, ISO 8402 (AFNOR 1994) and ISO 9004 (AFNOR 1993). In this definition, a process is viewed as a collection of activities and means designed to take one or more inputs to produce an output; the means can include personnel, infrastructure, procedurals information and methods.

We use the Porter’s value chain model to select the processes that can influence the generated value, that have a potential significant financial impact and/or where weaknesses have been identified. Doing so, we try to stay focus and avoiding to get lost into too many details, which is often the cause of the failure for numerous reengineering project (Hammer et al. 1993).

To describe the processes, our framework is based on the logical diagrams (Cattan et al. 1998). They identify the different actors and their responsibilities, the different activities, the logic and the timing between them and the exchange products. We also add the exchanged information (Di Martinelly et al. 2005).

The Figure 18 is an illustration of one of the logical diagrams we get through the analysis of the patient's process. The logical diagram was validated by the OT head nurse. We will give more details in the chapter 4.

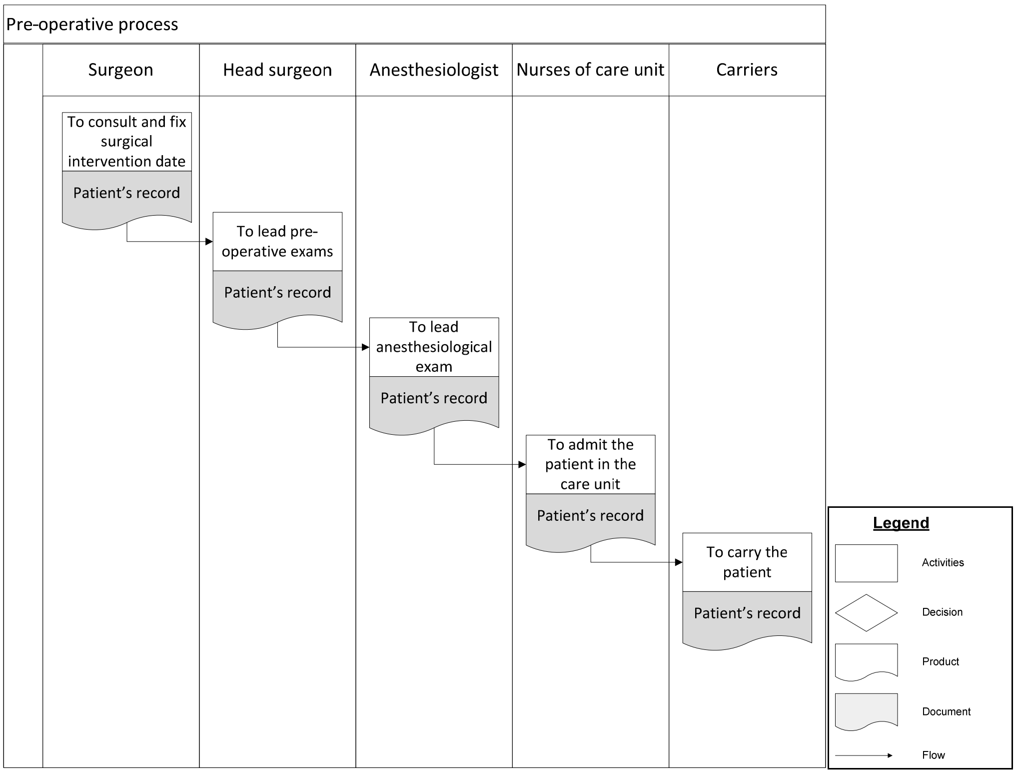

Figure 18. Logical diagram illustration

The drawing of the logical diagrams is done in 4 phases:

- Phase 1: this first understanding of the processes is done through the Porter's value chain that provides a first insight into the system, identifies the different potential actors and gives an overview of the rough process working.
- Phase 2: the different actors are met and are interviewed. The questions are about their responsibilities, the documents they have to fill in and the chronology between the different activities. They are asked first to stay close to the event, without given their points of view of the possible weaknesses. The aim is to have the more objective view of the processes to build the logical diagrams.
- Phase 3: the graphical representations are built and then submitted to the different actors. Most of the time, this first representation is modified. The logical diagrams are then updated on basis of the remarks.
- Phase 4: the updated processes are submitted to the different actors for validation during a meeting. At that time, the points of view of the different actors are asked to identify dysfunctions and weaknesses.

We choose the logical diagrams to represent the processes because it applies an easy graphical formalism, which doesn't require specific knowledge and which is a good medium to communicate. It also helps to establish a shared and generally accepted vision of the way the system is working. The hospital actors have therefore the opportunity to commit themselves in the analysis even if they don't have time to invest. They are so more willing to give information. However, the choice of that formalism has also some limits. The simple formalism limits the information that is shared; there is for instance no information about the time required by an activity. In addition, the choice of the formalism implies a risk of reification in the sense that the graphical convention introduces one analysis point of view (Claveranne et al. 2004).

The building of the logical diagrams provides an understanding of the system working and helps to build the different parts of the knowledge model: they identify the exchange information and the decisions rules to build the logical model and the decisions model; they identify the different responsibilities used in the value model to set the objectives. After having identified the strategy to follow, it is needed to define the objectives and the indicators giving the management the tools to assess and to drive the performance of the system towards the mission.

2.4 Building the scorecard

The scorecard is an instrument giving a perception of the system performance at a given time. It provides the manager a measurement tool, giving indications when there are deviations from the objectives and indicating the corrective actions to take. It also serves as a communication tool (Fernandez 2003). The scorecard is therefore based on 3 elements: the objectives, the indicators and the action plan.

The objectives are deduced from the strategy and their evaluation is made through performance indicators. The indicators definition is not easy and their links to the established objectives at the different decision levels is not explicit. Therefore, the managers need a measurement framework to help them to apply the strategy at the various decision levels and to properly define the corrective actions to undertake when necessary. A good knowledge of the system is also required, which is acquired through the logical diagrams.

2.4.1 Measurement framework

Measurement frameworks are designed to help organizations to identify and define a set of performance measures that appropriately reflects their objectives. The roles of the metrics are to interpret and describe quantitatively the efficiency and the effectiveness of their system. Different measurement frameworks have been developed so far. SMART (Cross et al. 1989) (Strategic Measurement Analysis and Reporting Technique) stresses the need to link corrective actions to the objectives and the strategy , to integrate financial and non financial information and to use internal and external performance measures. However, this framework was only applied to manufacturing system and doesn't define how to translate the strategy into different objectives. The "tableau de bord" performance management system was created in France more than 50 years ago. Its developers, process engineers, were looking for ways to improve their production process by better understanding cause and effect relationship. One of its main drawback is that it is most of the time finance-oriented (Epstein et al. 1998).

The SCOR model (Inc 2005) also proposes a framework for linking business objectives to supply chain operations. It contains a standard description of management processes, a framework of relationships among the standard processes, standard metrics to measure process performance, management practices that produce best-in-class performance and a standard alignment to software features and functionality (Huang et al. 2005). Thirteen performance measures are predefined and grouped in five categories: reliability, responsiveness, flexibility, costs and assets. They characterize the processes performance from a customer- and internal- facing. These indicators, developed for the industrial context were applied to the clinic pharmacy (Taher 2006). We have also tried to apply it to the hospital (Di Martinelly et al. 2006b). We were forced to recognize that the application to the patients' flow was not obvious. In addition, this task was even more difficult when we were trying to take into account the different stakeholders' perspectives.

The balanced scorecard, often abbreviated by BSC, was introduced by Kaplan and Norton (Kaplan et al. 1992; Kaplan et al. 1996b). It is based on the acknowledgement that financial indicators are insufficient to monitor a company. It uses a "cause and effect" logic to deduce the objectives from the strategy. The balanced scorecard has been successfully applied to hospital for instance to measure the performance of an outpatient clinic (Curtright et al. 2000), or to support the project of a partnership between hospitals (Hageman et al. 1999). The construction of the BSC framework supposes that the company has already a strategy (Bessire et al. 2005). We briefly describe the BSC framework and the tools we use to build it.

The BSC is a framework for translating strategic objectives into performance measures and strategically aligned initiatives. The organization's mission and strategy are decomposed into strategic objectives and measures around four perspectives: (1) financial, (2) customer, (3) internal process and (4) learning and growth. These perspectives are represented in the Figure 19.

- The financial perspective assesses the economical consequences of the past decisions based on the turnover, profitability, liquidity.
- The client's perspective focuses on the client's satisfaction and fidelity and the balance between the provided services and the needs and expectations.
- The internal processes perspective aims at optimizing the products and service delivery in terms of quality, costs, time and flexibility to increase the client's satisfaction and the economical return.
- The learning perspective concerns the core competencies and skills, the technologies and the corporate culture needed to support an organization's strategy.

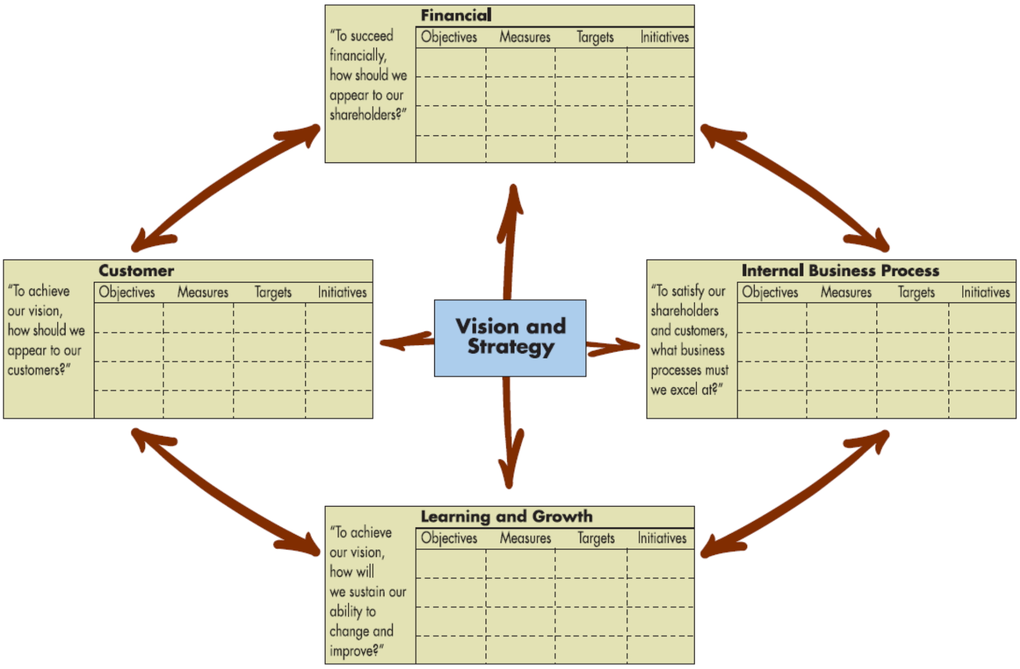

Figure 19. Translating vision and strategy four perspectives (Kaplan et al. 2007)

For each objective, the indicators and the target value to measure the achievement are defined. In addition, there is also a need to determine the actions/initiatives to take to drive towards the targets.

The framework provides a balance between short- and long-term objectives, financial and non financial measures, and external and internal performance indicators. Most importantly, the scorecard balances the outcomes the organization wants to achieve, and the drivers of these outcomes (Kaplan et al. 1996a). The outcomes reflect the common goals of many strategies. These generic measures include profitability, market share, customers' satisfaction and employees' skills. The performance drivers reflect how the company puts in practice the strategy to get a competitive advantage. Outcome measures without performance drivers do not communicate how the outcomes are to be achieved. They also do not provide an early indication about whether the strategy is being implemented successfully. Conversely, performance drivers without outcome measures may enable the business unit to achieve short-term operational improvements, but will fail to revel whether the operational improvements have been translated into expanded business with existing and new customers.

For instance, a typical outcome measure is the revenue or the profit. Considering an example coming from the hospital, we can state that the revenue of the pharmacy is an outcome measure. One way to improve its revenue is for instance to improve the accuracy of the billing, which is a performance driver. By monitoring only the indicator of the revenue, the manager can not know if an increase in the revenue is due to an improvement of the billing accuracy or is due to an increase of the activity. In the same way, by monitoring only the billing accuracy, the manager has no idea if this operational improvement will lead to an increase of the pharmacy revenue.

A cause and effect reasoning links the drivers of the strategy to the desired financial and customer outcomes that represent the success of the strategy.

A thorough understanding of the working of the company and of the different processes is needed. This is acquired through the building of the knowledge model.

2.4.2 Building steps

Even if the BSC have been widely applied in firms, its implementation is not so obvious. The authors (Kaplan et al. 1996a; Kaplan et al. 2007) recognize that even with the use of cause and effect logic, it is not easy to link the strategy to different objectives and to define indicators that provide outcome measures and performance drivers of these outcomes. In addition, there is no way to link the performance metrics to the processes and therefore to identify the responsibilities. We therefore use the following approach to link the best way possible the objectives to the different axes and to the processes. We suggest following these steps that will be applied on concrete examples in the chapter 4.

a. Translate the strategy into the objectives at the different decisions level, identify for each objective the processes and the activities that are involved and the people responsible for these activities; identify for each objective the actions to take when the objectives are not met.
b. Link the objectives to the different axes of the BSC and ensure that all axes are represented. The different objectives are linked together through a cause and effect relation. Then, for each objective, identify the indicators to assess it.

a. Objectives translation, responsibilities identification and corrective actions

The objectives should drive both behavior and performance. They help to focus the organization arriving at the strategic destination. The corrective actions are the actions to undertake when the objectives are not met. Objectives and corrective actions are not easy to define and both require a good knowledge of the system, which is acquired through the knowledge model building. Two tools are used to identify and define them: the connectance diagrams from the TAPS methodology (Tan et al. 2003) and the logical diagrams that were explained in 2.3 of this chapter.

The TAPS methodology (Tool for Action Plan Selection) was developed by the Institute for Manufacturing, Cambridge University, to create a formal visual model to develop a common perception of the operating environment, which is the basis for action planning. The approach is supported by a set of tools for gaining insight and understanding of complex problems and making decisions taking multiple criteria into account. One of these tools is the objective-variable connectance diagram that we adapted to our case to make easier the objectives translation and the corrective actions identification. The connectance diagram is a graphical hierarchical representation. The construction of the connectance diagrams starts from the general objectives, identified in the literature, and that are general outcome measures. For each of these objectives, we identify the different resources aspects, the means used to achieve it. The variables having an influence on the aspects are then identified. These variables will help to define the objectives at a more detailed level and are the performance drivers, specified to the studied system. For each variable, we have to identify the potential actions that could be taken to change the value. The Figure 20 illustrates a connectance diagram built for an objective.

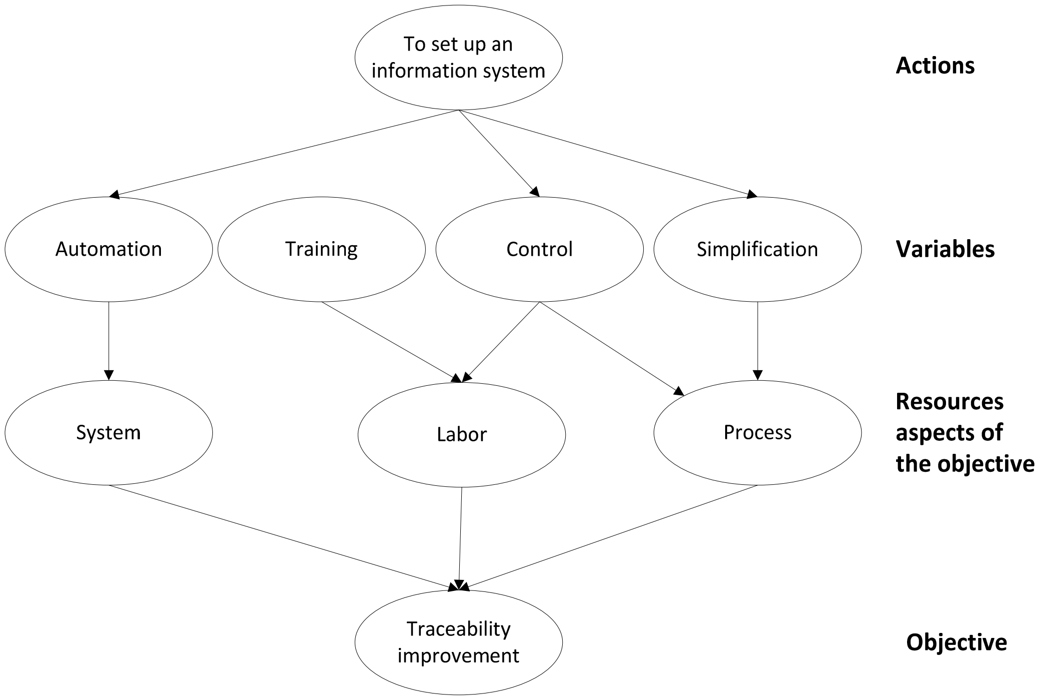

Figure 20. Illustration of a connectance diagram

In that example, the objective is the traceability improvement. There are three aspects at this objective: the system, the labor and the process. The system refers to the infrastructure that is used to register the patient's information. The labor makes reference to the nurses who are recording the information for the patients. The process refers to how the information is registered. To increase the efficiency of that aspect, the simplification of the process or the setup of more control could help to improve the number of patient's recorded files. To do so, the setup of an information system could lead to the simplification of the process (fewer activities) and to a better control. This system could also lead to an automation of the system (scanning) that would improve the system working. By providing the nurses with the appropriate training and adding more control, the traceability of the medicines could also be improved. The identified variables, automation, training, control and simplification will serve to define the particular objectives for the hospital of our concern.

After having identified the objectives specific to the system under consideration and the corrective actions to take, we have to assign responsibilities. A good objective should be reachable. The decision maker who is assigned an objective shall have the means to reach it. We identify therefore for each objective the different processes that are implied and the responsibilities assigned to the different activities of the processes. This information is given by the logical diagrams we built in the previous phase.

b. Linking objectives to the BSC axes and indicators definition

After having identified the actions for each objective, we link each objective to one of the axes of the balanced scorecard. We represent that using the strategy map (Kaplan et al. 2000). The aim is to ensure that all objectives are linked by a cause and effect relation and that each objective within each perspective is achieved by realizing the objectives of the other perspectives. The logic linking the objectives is based upon an “IF-THEN” sentence. IF ‘objective A is accomplished’ THEN ‘objective B is positively impacted’. If there is a break in the chain, the objectives definition is reviewed.

The map provides a visual representation of hospital critical objectives and the crucial relationships among them that drive organizational performance. It shows the cause and effect links by which specific improvements create the desired outcomes. The Figure 21 illustrates the strategic map we construct to evaluate the pharmaceuticals dispensing. For instance, if the accuracy of billing is improved, it will increase the income of the pharmacy. If the income of the pharmacy increases, it will have a positive impact on the profitability.

The strategic map helps us to visualize the links between the different objectives and to be sure that all perspectives are represented. We have then to define for each objective the performance metrics.

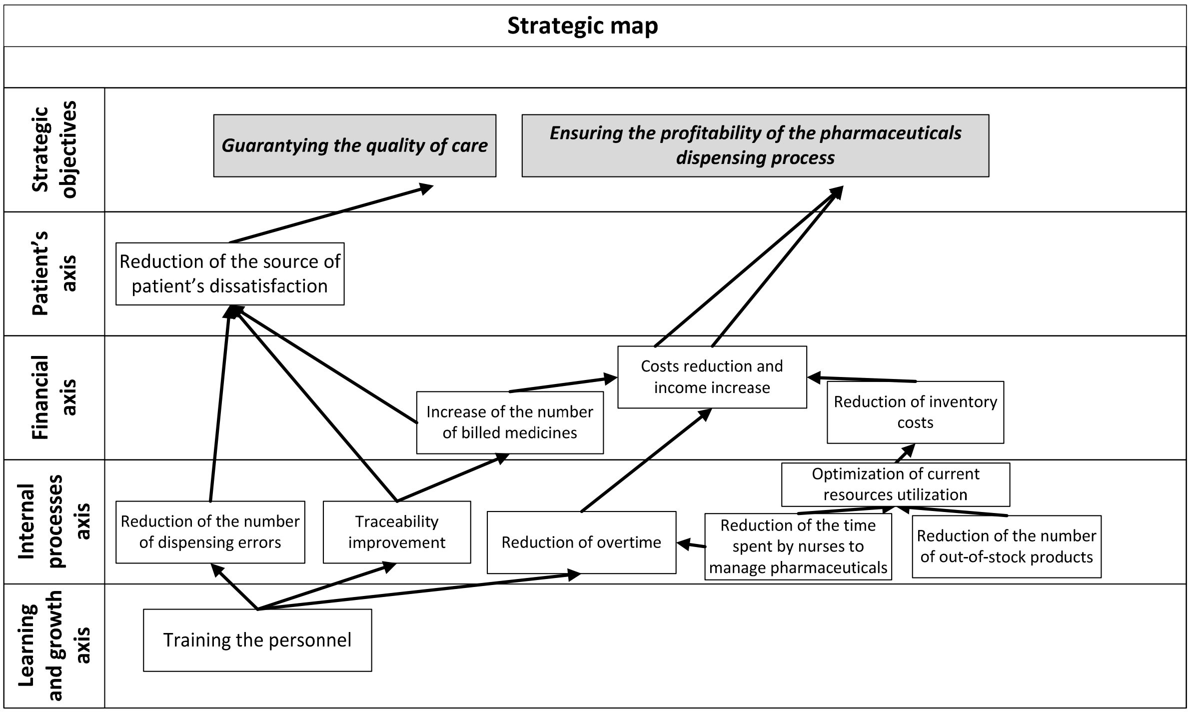

Figure 21. Illustration of a strategic map – the pharmaceuticals dispensing

A wide variety of indicators could be defined. We base ourselves on indicators already applied and validated in hospitals. We therefore use as reference the work of Li and Benton (Li et al. 1996). They did an extensive review of the literature about the different indicators used in a hospital and they organized them according 4 perspectives: financial perspective, quality perspective, internal and external views. The point of view of the different stakeholders is therefore taken into account, respectively, the management, the medical staff, the regulator and the patients. We present the taxonomy in the Table 4.

Table 4. Performance measures taxonomy (Li et al. 1996)

	Cost/financial performance	*Quality performance*
Internal measures	- Production efficiency - Utilization	- Process quality - Service quality
External measures	- Financial status - Market share	- Customer perceived quality - Customer satisfaction

- Internal cost measures are mainly related to production efficiency and utilization issues. The measures of productivity efficiency are complex measures because of the difficulty in quantification and are most of the time based on hospital length of stay or case mix. Statistical and cost accounting methods are commonly used to measure production efficiency. Utilization measures the degree to which work forces, facilities and equipment are used. For instance, the utilization rate of beds is the number of occupied beds divided by the number of subsidized beds.
- Internal quality measures are related to the quality of the care process, if the medicine is properly practice or not, and related to the service characteristics, the direct output of a process, measured by improved health.
- External financial measures are mainly done by external institutions and include typically liquidity, profits or market shares.
- External quality measures include the quality perceived by the patient and his satisfaction towards the received care. These measures are studied together to identify differences between the ideal quality a consumer has and the actual service quality the consumer has experienced.

The different indicators are then selected and validated with the actors from the hospital.

2.5 Conclusion

To reorganize the supply chain activities of the hospital, we need a framework to describe and assess the current system working, and to propose improvement solutions that have to be evaluated before being implemented. Because of the multiple stakeholders that are involved in the hospital decisions making and who have different point of views, we find it particularly important to have a well defined and shared value and performance system. We choose to enrich the ASDI framework with a value and performance model to ensure that the defined performance indicators appropriately assess the proposed solutions.

The value and performance model is embedded in the building of the knowledge model. This one is aimed at understanding the working of the system, identifying the critical activities, describing processes and management rules, identifying resources and diagnosing weaknesses. The knowledge modeling should also provide the user a framework to define the performance indicators to assess the system based on metrics in accordance with the value system. We suggest therefore an approach in five steps that is schematized in the Figure 22.

The first step of the value and performance model is the Porter's strategic analysis. It highlights the influence of the environment on the strategy adopted by a hospital. This analysis showed us that the focus on the supply chain activities was a good way for hospitals to satisfy their mission, providing care of quality while keeping costs under control, whatever the strategy they want to pursue.

The second step, the Porter's value chain, emphasizes the links existing between the hospital main value chain, the care creation, and the clinic pharmacy. It helps us to emphasize the links between the different value chains and to select the processes to analyze in more details.

The third phase, the processes description, is made through logical diagrams and is concomitantly led with the value chain analysis. It provides us with more insight into the working of the activities and their chronology, the identification of the different responsibilities and of the weaknesses in the current working. It also serves as a good communication tool, based on a simple formalism understandable for most actors. The logical diagrams make it also easier to implement the changes by involving the stakeholders in the project and by objectifying the practices.

The fourth phase is the objectives translation. Starting from the general objectives deduced from the strategy, we use the connectance diagrams to identify the variables that have an influence upon these general outcome objectives. These variables define the specific objectives, the performance drivers. For these last, we identify the different processes implied and we point out the responsibilities thanks to the logical diagrams.

The last step is the building of the scorecard using the balanced scorecard framework. The objectives we've identified in the previous step are linked to the different axes of the balanced scorecard and the cause-effect relationship is verified to ensure that all objectives are going in the same direction as the strategy. The performance indicators for each objective come from the literature and are selected and validated by the actors.

These indicators provide measures to assess the current system and its weaknesses and will serve to assess the proposed solutions. The action models replicate the working of the system and evaluate the impact of the different solutions before their implementation thanks to the indicators.

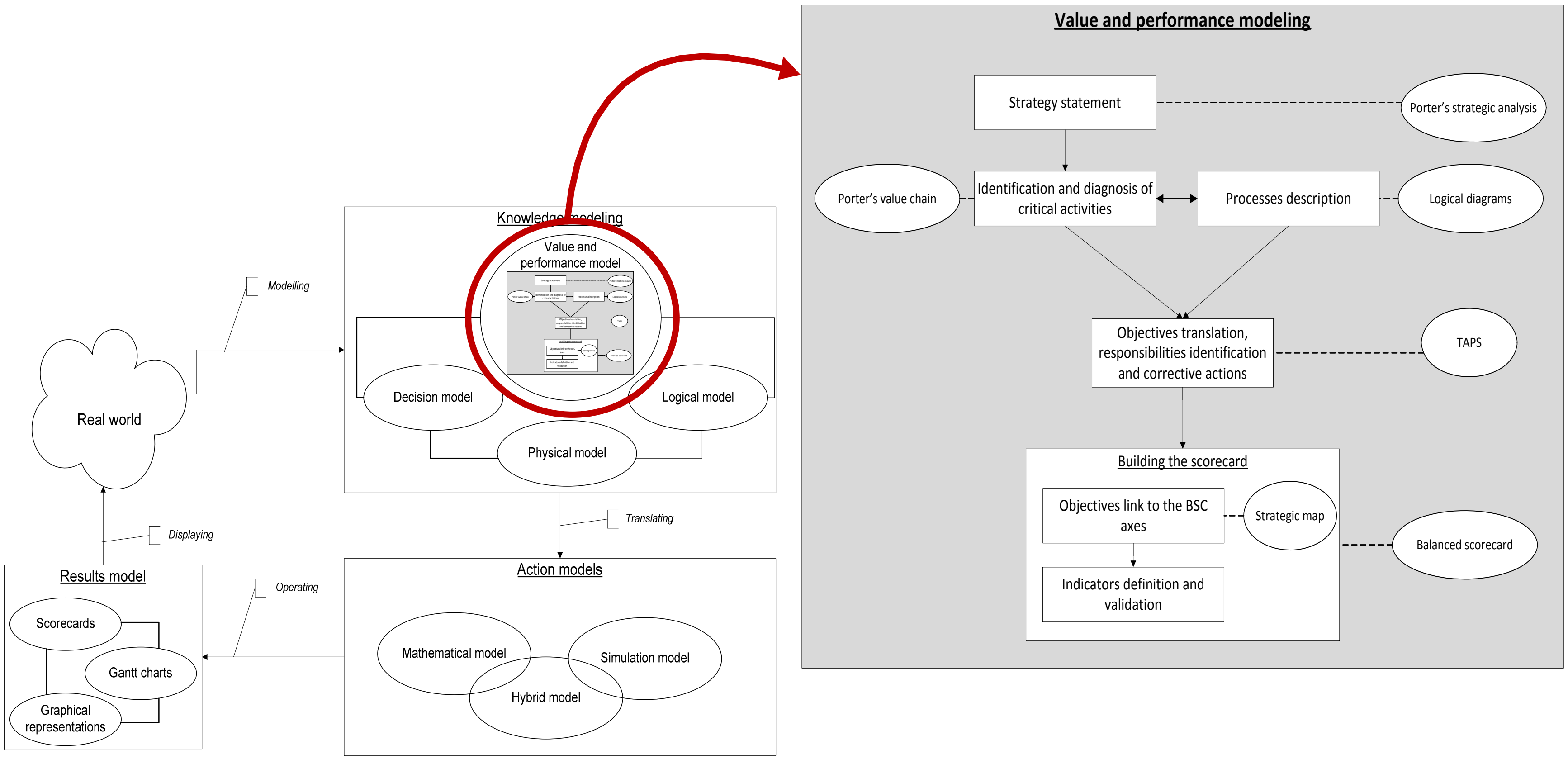

Figure 22. Suggested methodology

Chapter 4. Methodology application

1 *Introduction*

In the previous chapter we detailed the methodology we suggest to design and evaluate solutions suitable for health care organizations. We deploy the methodology described previously in order to build a deep knowledge model for the Belgian University hospital we are working with. This model consists in establishing the AS-IS situation of the pharmaceuticals dispensing system and of the medico-technical units working, the ER[4] and OT[5]. It provides more insight into their working, it helps to identify the critical activities, to describe the processes and management rules, to identify the different resources that are involved in the processes and to define the performance indicators to assess the proposed solutions.

2 *Knowledge modeling*

The application of the Porter's strategic analysis that we led in the chapter 3 showed us that whatever the strategy chosen by the hospital managers, they have to look for solutions to reduce their costs while improving the quality of the service provided to the patients. We also noticed that the ways to reach this goal have been addressed differently by American and European hospitals because of the structure of the health care system. American hospitals are competing in a rather private-like environment and decide to improve their supply chain to reduce their costs, as many private companies. As underlined, we think it is a good strategy but it is important to know how to assess it because the hospital cannot be evaluated solely on basis of the costs.

[4] ER : Emergency Rooms
[5] OT : Operating Theatre

The Belgian hospital of our concern is launching a project to build a new logistical platform. The project will impact the logistics activities throughout this health care organization. Because of the implications of such project, the management wants to evaluate it before its implementation to be sure that it will help the hospital to reach its strategic objectives. However before translating the strategy into objectives and defining the performance indicators, we have to better understand and diagnose the working of the current system. We will focus as previously explained on the pharmaceuticals dispensing dedicated to the ER and to the OT.

2.1 Logical, decisional and physical model

2.1.1 The pharmaceuticals dispensing to the medico-technical units

The law governs the pharmaceuticals dispensing in Belgium. The pharmaceuticals delivery system is under the responsibility of the clinic pharmacy. The medicine has to be delivered nominally, on prescription. There is however some exceptions to this rule for units dealing with emergency cases: these units are allowed to use a dispensing cabinet. These cabinets are replenished globally, without using a priori prescription. They are set up in care units like emergency rooms, intensive care units, operating rooms, neonatology, delivery rooms, medico-technical units and doctor's office. For all these rooms, an inventory of medicines might be kept to satisfy any demand.

Different kinds of decisions are taken regarding the inventory management decisions for the medico-technical units. These decisions are listed in the Table 5 where the people in charge of these decisions are put between brackets. Level 1 decisions are related to strategic decisions about the inventories as the type of investment to do and the information system to use. The level 2 concerns the tactical decisions related to the distribution system and the quantities to keep in stock. At level 3, the actors take the day-to-day decisions concerning the medicines. For each of these decisions, we also give observations on how they are currently taken.

The Figure 23 describes the pharmaceuticals flow. In this figure, we represent the emergency rooms but this schema stays valid for the operating rooms. The nurses take the prescribed pharmaceuticals from the inventory located on the shelves in the medico-technical unit. This inventory is replenished two times a week from the pharmacy, based on the consumed items. At the end of the month, the pharmaceuticals are replenished to the PAR level[6]. The central pharmacy is located in another building and manages its inventories using a kanban system. This inventory is re-supplied from various vendors. The lead times are variable.

The pharmaceuticals dispensing processes have been described through logical diagrams (Di Martinelly 2005). The methodology used to build them was described in the chapter 3. These logical diagrams have been constructed on basis of interviews of nurses in the ER, OT and the pharmacists. They identify the different actors and their responsibilities, the different activities, the logic and the timing between them. It also allows identifying the products and information. Three processes have been identified and are also located in the

[6] Reorder point policy in the health care sector

Figure 23. These processes have been described using the logical diagrams: one process for the medical dispensing, one process for the ordering of pharmaceuticals and one process for the billing (but different for the outpatients and inpatients). The logical diagrams representing the different processes are displayed on page 65.

Table 5. Decisions about the management of inventories in the ER

Type of decisions	*Activities/responsibilities*	*Observations*
Level 1	Inventory system setup (clinic pharmacist)	- Pharmaceuticals kept on shelves using a traditional inventory management system based on EOQ quantities. - No integration between the clinic pharmacy and the emergency rooms - No information system - Dispensing regulated by law - Kanban system used at the clinic pharmacy
Level 2	Delivery frequency (clinic pharmacist)	- Replenishment 2 times a week based on the orders of the nurses - One time a month, the PAR level are refilled
	PAR levels setup (nurses)	- Determination of the PAR levels based on experience
Level 3	Replenishment orders (nurses)	- Quantities to order each period determined through the number of medicine consumed (written in the patients' file)

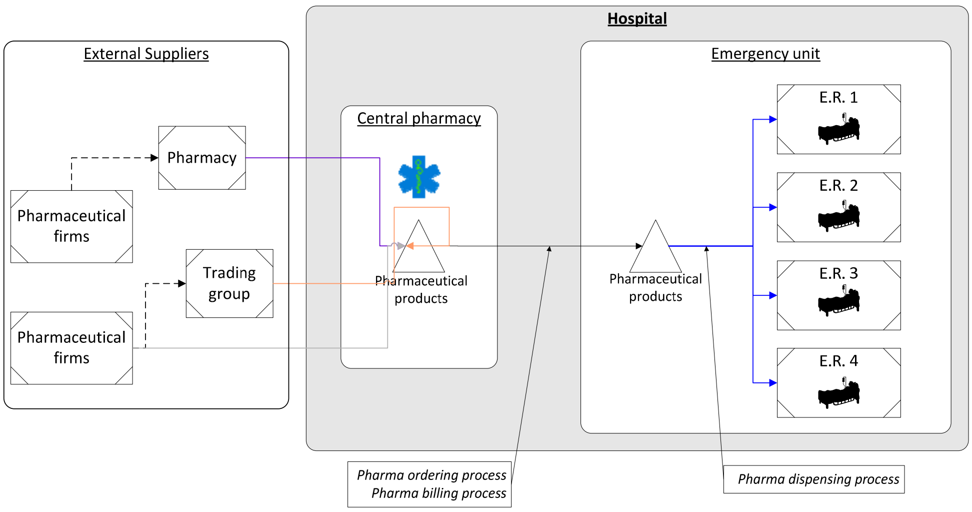

Figure 23. Pharmaceuticals flow for the emergency unit

For each logical diagram, we identify the actors, the activities, the products and the documents.

♦ ***Pharmaceuticals dispensing process***

- Identification of the actors
    - Physician
    - Nurses
    - Pharmacist
- Identification of the activities
    - Prescribe: the physician prescribes the pharmaceuticals.
    - Make: if the prescribed medicines are available on the shelves in the ER, the nurses prepare the pharmaceuticals for the patient.
    - Dispense: the nurses administrate the pharmaceuticals to the patient.
    - Fill in: after having dispensed the pharmaceuticals, the nurses write the administrated medicine in the patient’s record. Then, they fill in the pharmaceuticals list.
    - Order: if the pharmaceuticals are not in the ER, the nurses place an emergency order.
    - Deliver: the ordered pharmaceuticals are carried to the ER thanks to the carriers.
- Identification of the products and documents
    - Prescription
    - Pharmaceuticals
    - Patient’s record: file of the patient in which nurses write all clinical information as well as the medicine dispensed.
    - Pharmaceuticals list: the pharmaceutical list is the list of all medicines consumed by a patient. This document serves as the basis for the replenishment of the shelves in the ER and for the billing.

♦ ***Pharmaceuticals ordering process***

- Identification of the actors
    - Physician
    - Nurses
    - Carriers
    - Pharmacist
    - Invoice responsible
- Identification of the activities
    - Check the inventory: the nurses check two times a week the inventory level. If the level has reached the ordering level, they place an order.
    - Order to reach the PAR level: the nurses order to reach the PAR level and they fill in a medical ordering form.
    - Validate: the physician has to validate the medical ordering form.
    - Gather: the medical forms are gathered by the pharmacy carriers during their rounds twice a week.

    - Prepare order: the pharmacist prepares the order and specify on the medical ordering form if the products are delivered or not.
    - Invoice: a copy of this ordering form is sent to the billing service that invoices the amount of products to the ER.
    - Supply: the pharmaceuticals are delivered to the ER 2 times a week by the carriers.
    - Resupply the inventory: the nurses put away the pharmaceuticals in the dispensing cabinet.

- Identification of the products and documents
    - Medical ordering forms
    - Pharmaceuticals ordering forms
    - Invoice for the medico-technical units

♦ ***Pharmaceuticals billing process***

- Identification of the actors
    - Carriers
    - Nurses
    - Pharmacist
    - Billing responsible

- Identification of the activities
    - Fill in: each time a nurse dispensed a pharmaceutical to a patient, she has to fill in the patient record and the pharmaceuticals list with the dispensed medicines.
    - Sort: the billing process is different for the outpatients and for the inpatients. The inpatients files are sent to the pharmacy while the outpatients files have to be sent to the invoice department.
    - Pick up: the carriers take all the documents during different rounds.
    - Set the price: for the inpatients, the pharmacy do a "pre-invoicing". Once a month, they send the information recorded about the patient's pharmaceuticals consumption to the invoicing department.
    - Invoice: the inpatients receive an invoice with the amount to pay for the stay in the hospital and for the dispensed pharmaceuticals.
    - Pick up
    - Set the price and invoice: the different services are billed to the patients by the invoicing department. The price of some medicines can be different depending if the client is an inpatient or an outpatient.

- Identification of the products and documents
    - Patient's record
    - Pharmaceuticals list
    - Patient invoice.

♦ ***Logical diagrams***

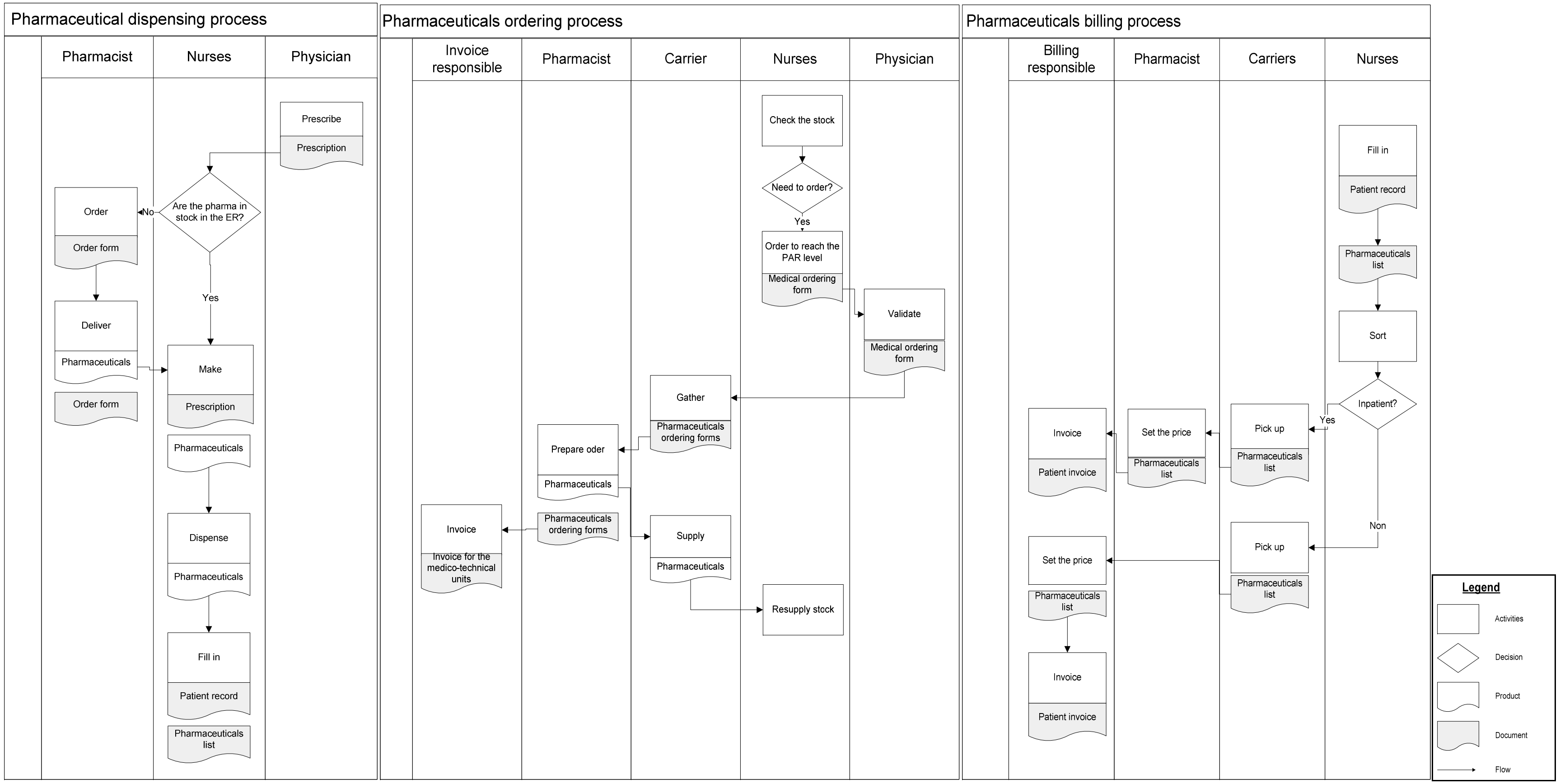

Figure 24. Pharmaceuticals dispensing, ordering and billing processes

However, we have to notice that the pharmaceuticals demand pattern of the OT and the ER are different. The demand for pharmaceuticals in the ER is completely random; the number of patients and their pathologies are unknown. On the contrary in the OR, the pharmaceuticals consumption is dependent upon the surgical procedures led, which are for most of them known one week ahead. The demand will be influenced by the way the surgical interventions are planned and scheduled. We will thus explain now in more details how the OT is working since it will influence heavily the inventory management policy of the pharmaceuticals.

2.1.2 *Operating theatre*

The organization of the OR activity is based upon the assignment of a day, a room and a starting time to each patient's surgical procedure. The patient is therefore at the center of the process.

An operating theatre is normally composed of operating and recovery rooms. It is one of the most costly medico-technical units. The Figure 25 represents the interrelations that exist between the OR and the other services of the hospital. The OT activity influences the resources consumption throughout the rest of the hospital (Beliën et al. 2006). If a medical specialty has more surgical procedures, it increases the number of resources required as more beds, more nursing activities and more medical exams. The OT can be seen as the engine that drives the hospital. The OT activity is supported by logistical and administrative units.

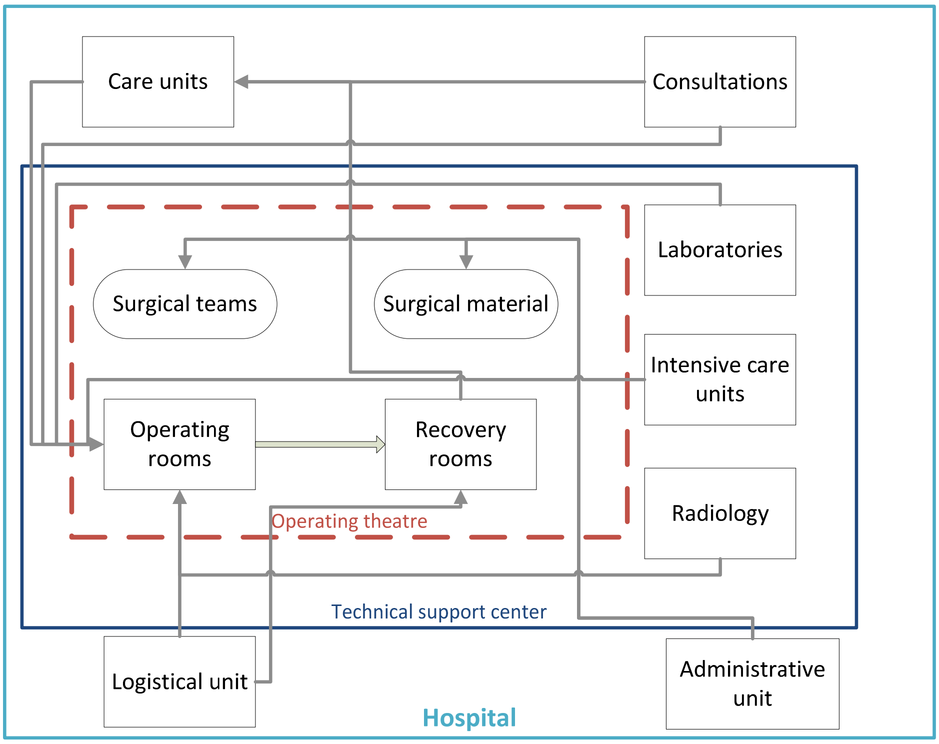

Figure 25. Interrelations between the operating theatre and the other care units (Fei 2005)

Since the OT activity drives a good part of the hospital activity and requires numerous human and materials resources, the way the available time of operating rooms is utilized will influence the way these resources are managed. There are three different operating programming models (Kharraja 2003). Each defines a way to organize the working of the operating rooms:

- The open scheduling uses a first come-first served basis for request of operating room time; a surgery can so theoretically take place in any OR at any time during the opening hours.
- The block scheduling reserves large blocks of uninterrupted time for surgeons, during which several operations may be performed; the surgeries of a surgeon are scheduled during that particular time.
- The modified block scheduling is a block scheduling with reallocation of unused time to other surgeries.

In hospitals we visited in the USA and in Belgium, the OR is most often managed according to the block scheduling policy. The management considers that an operating room can be used by any surgical specialties. In reality however, they are only occupied by few specialties because of the specific equipment needed to do the surgeries (we think about the specific materials for neurosurgery or orthopedics for instance).

As we mentioned it, the patient is at the center of the OT activity, and so of the different processes. The operative process is composed of 3 processes: preoperative, peroperative and postoperative processes. These processes are not necessary continuous. The patient can undergo the preoperative process some days before the surgery and be admitted only before the surgery.

The preoperative process is made of the activities realized until the day before the surgery. These are the required medical exams to decide if the patient can undergo the surgery or not. To do these exams, the patient can already be admitted within the hospital or not. If the patient goes successfully through the process, the patient is assigned an admission day for the surgery. The per-operative process concerns the activities that are undertaken when the patient is in the operating room. The postoperative process that follows immediately the per-operative process, is related to the care activities dispensed after the surgical intervention: depending the health condition of the patient at the end of the surgical procedure, he may stay in the recovery room or in the intensive care unit.

The different processes have been represented through logical diagrams (Figure 26). The different activities through which the patient goes are identified as well as the actors who are responsible for those.

♦ *Logical diagrams*

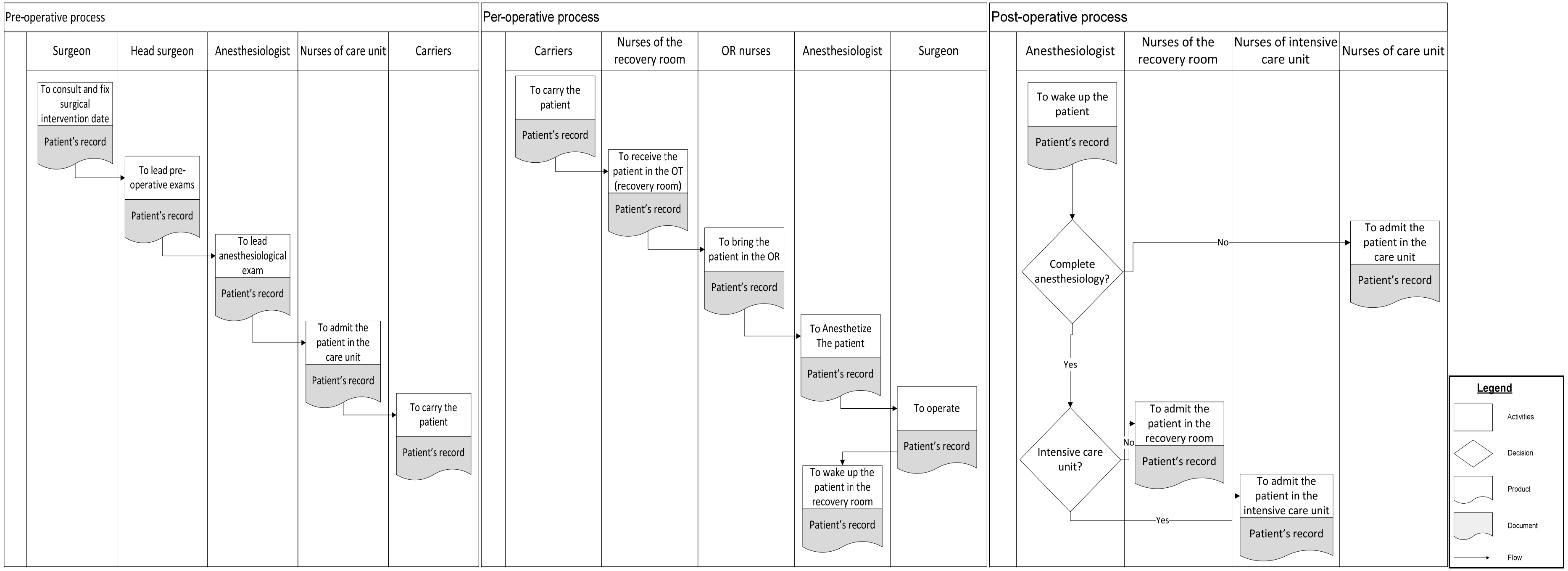

Figure 26 Patient's processes description in the OT

The achievement of these processes is depending upon the coordination of multiple resources, resulting from a number of decisions taken at different levels. The management of the OT deals with the planning and scheduling of the surgical interventions, putting all together at the same time and in a same space the necessary resources (materials, personnel and information) to lead a surgery (Thorin 2003).

The different decisions are classified according to the time horizon over which they are valid and according to the type of resources concerned. They are presented in the Table 6. The decisions at level 1 are valid for at least 1 month and are a constraint for the decisions taken at level 2. These one are most of the time taken every week. The level 3 deals with the day-to-day operations. At each level, we indicate the resources concerned, the decision levels and the responsibilities.

Table 6. Decisions about the management of the operating theatre

Type of decisions	*Resources*	*Activities/responsibilities*	*Observations*
Level 1	OR	Block time allocation (OR manager)	- Block time allocation to surgical specialties - Allocation by block of half-day according to the activity of the surgeons
	HR	Monthly time tabling (OR head nurse)	- Monthly time tabling for nurses - Depending of the block time allocation to surgical specialties to determine the number of scrub nurses
Level 2	OR	OR planning (OR manager)	- Elective surgeries planning
	HR	Nurses allocation (OR head nurse)	- Allocation of nurses to OR based on their competencies - At least 3 nurses by OR, one of whom is a scrub nurse
	Care units	Bed booking (care units head nurses)	- Beds booking for patients in the care units
Level 3	OR	OR scheduling (OR manager)	- Elective surgeries scheduling and emergency surgeries management
	Blood	Blood ordering (OR head nurse)	- Blood ordering

Concerning the pharmaceuticals resources, we refer to the Table 5 since their management is identical in medico-technical units allowed to use a dispensing cabinet. This time however, the demand for the pharmaceuticals is not random but follows some patterns triggered by the planning and scheduling of surgical interventions. Indeed, at each surgical procedure, is associated a “preference card” or “preference list”, which is a combination of the physician’s preferences for materials and the patient’s needs for materials. During a patient’s surgical procedure, the consumed quantities may vary , which is referred by (Roth et al. 1995) as the stochastic bill of materials for surgical procedures. The preference list can be standardized. In that case, that means that for each surgical procedure, one preference list is used by all surgeons, which lead to a significant reduction in the number of references used in the OT.

There is on average 80% of elective surgeries in the hospital we visited. All these surgeries are known and programmed one week ahead. The current management of the OR is a block scheduling policy which is convenient for labor planning and improvement of key resources utilization. When this policy is combined with steady-state inventory management policy, it degrades the performance of the system because it triggers a surge in the demand. For instance, high cost orthopedic materials may be in high demand on one day out of every two weeks, and in very low demand for the rest of that time. However, the high service requirements of the item coupled with its non-stationary induced by demand uncertainty, will drive a large amount of safety-stock for that item. We observed this discrepancy in all of the hospital we interviewed. The OT and ER inventories cannot be definitely managed with the same policy.

2.2 Value model

The operating theatre and the emergency rooms are medico-technical units directly implied in the care process of patients while the pharmacy is responsible for the pharmaceuticals dispensing process. It seems clear that these units are linked together but the models we've used so far didn't provide us with that information. In addition, in order to make a diagnosis of the weaknesses and to identify what are the improvements opportunities, we have to define the performance measures to assess the current system and the proposed solutions. We base ourselves on the proposed framework in the chapter 3, Figure 13.

The strategic statement was given by the hospital management that wants to put the emphasis on the logistical activities as a way to reduce the costs while improving the quality of the service provided to the patients. The logical diagrams that were built during the previous phase give us the necessary knowledge to lead the Porter's value analysis.

2.2.1 Identification and diagnosis of critical activities

We apply the Porter's value chain analysis to both the hospital main value chain, the creation of care, and to the pharmaceuticals dispensing process supported by the clinic pharmacy. Our objective is to understand the links between the ER and the OT, and the pharmacy. We group together on basis of Porter's sub-categories the different activities we identified through the process descriptions we made by the logical diagrams. The results are shown in the Figure 27.

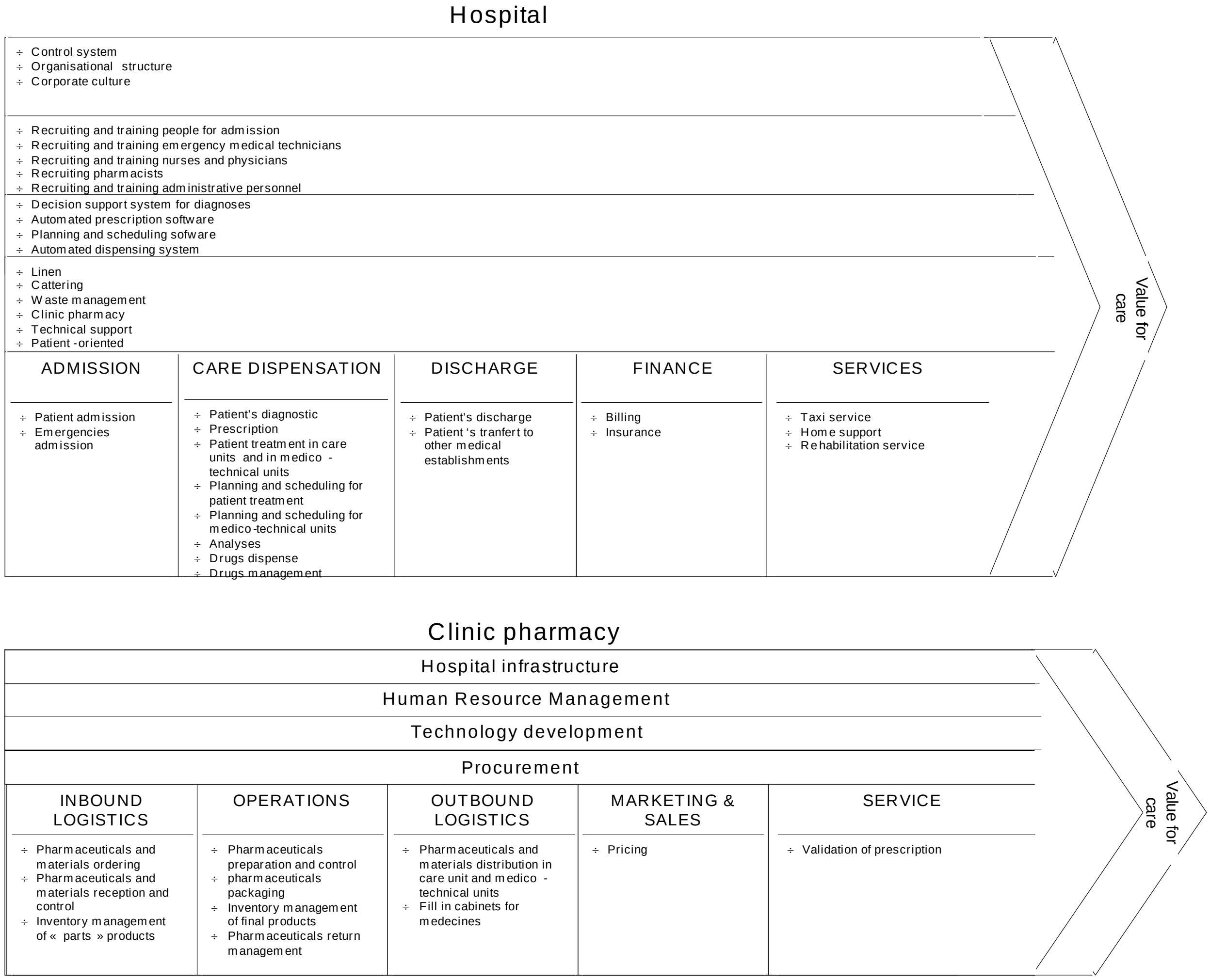

Figure 27. Porter's value chain analysis for the clinic pharmacy and the hospital

The ER and the OT are often considered as the drivers of the hospital activity since their activity levels generate resources consumption throughout the hospital, as beds, personnel and pharmaceuticals. They are both part of the hospital activity main value chain the "care dispensation" and are linked to other activities. The ER is one of the ways the patients get admitted in the hospital. It triggers the activity of the other medico-technical units (OT, labs, X-ray,…) and will also influence the hospital activity. Around 40 % of emergencies are hospitalized in a care unit (Di Martinelly 2001). The OT activity is dependent upon the availability and the workload of the other units. For instance, there should be enough rooms in the care units to admit a patient for a surgical intervention. All medical exams should have been done and the results given to the surgeons; there should be enough beds available in the recovery rooms to not keep the patients in the OR; the carriers should be available to carry the patients from the care unit to the OR and from the recovery rooms to the care units. The coordination of these activities should be ensured by the communication of the OT planning.

The activity of these medico-technical units is also dependent upon the support activities that should provide them with the necessary resources. For instance, the OT activity is dependent upon the number of OR available and the equipment installed (polyvalent rooms or not). The more OR there are, the most surgical interventions can be led. However, the OR working and maintenance are extremely expensive, which lead to limit their numbers. The management of the human resources for the OT deals with the determination of the needed personnel to run the operating rooms, the recruitment and the timetabling establishment. If there are not enough nurses, all the operating rooms cannot be open which can lead to a reduction of the available capacity.

The clinic pharmacy provides pharmaceuticals and sterile materials to the care and medico-technical units. The goal of the medication delivery system is to deliver the right dose of the right medication to the right patient at the right time through the right route (Mazur et al. 2007). The clinic pharmacy activities are highly intertwined with the hospital main activity and it is important to have a perfect coordination between these two flows. Here are some of the important links between the chains highlighted by the Porter's analysis:

- Inbound logistic activities from the clinic pharmacy: the pharmacist orders some products based on the admissions planning. For instance, he may contact the blood bank or order orthopedic materials for specific surgeries. This practice is unfortunately limited because there is little coordination between the admission planning and the clinic pharmacy.
- Outbound logistic activities from the clinic pharmacy: the care relies heavily on the availability of all products; any delay or products omission will impact the care dispensation, postponing the patient's treatment. By fear of running out of products, the medical units tend to set up PAR level as high as possible even if the pharmacy has enough capacity to manage these demands.
- Pricing at the pharmacy: the pharmacy prices the medicine dispensed to the inpatients and then communicate the information to the financial service to bill the patients. For the medico-technical units using a dispensing cabinet, the billing done will therefore depend upon the information transmitted to the pharmacy by the ER and OT. If this information is partially made, there will be important losses.

More specifically, the OT and ER activities are also highly intertwined with the clinic pharmacy that has to provide them with the needed materials and medicines. At the ER, all medicines should be available to meet any demand. To undergo a surgery, all materials and medicines should be there otherwise the surgical intervention could be postponed, putting the patient's life in danger and modifying the OR planning causing additional delays and resources reallocation (nurses, OR time, etc.).

The changes done in the pharmaceuticals dispensing can have a direct impact on the value creation for care, both in positive or negative aspects. The analysis we made so far helps us to identify some weaknesses and non value added activities:

- Redundancy of activities: this is the case of the billing activities made actually twice, once in the clinic pharmacy and once in the general billing service. These are over costs of labor. Furthermore billing processes are different according to the patient's type, inpatients or outpatients, which increases the risks of missing or confusion. Two types of mistakes are usually encountered: the pharmaceuticals are not billed, which increases the financial losses of the pharmacy, or they are wrongfully billed to patients, which causes clients' dissatisfaction. In both cases, a lot of money is lost and it can impact negatively the quality perceived by the patient.

- Poor integration of information within a unique system: this generates several problems: a traceability/quality problem, a financial loss and a less effective management of resources. A drug can be traced so far by either looking in all the patient's records for that specific drug or looking in the billing documents. If a dispensed drug was unfit for consumption, each patient that might have been contaminated should be contacted. This activity costs a lot of money and time and gives a poor idea of the quality of care. In addition, because of the multiple rewritings and potential mistakes, all medicines are not necessary indicated in the patient's record. It is particularly critical in medico-technical units as the ER and the OT where it is important to know what was/is the treatment given to the patient. Because of this poor information system, a number of pharmaceuticals dispensed to the patients are not recorded and not billed, which generates a financial loss for the pharmacy. This point is critical since the pharmacy is the third revenue provider of the hospital. The lack of integrated information system makes also the management of the resources more difficult; it is difficult to track the order of pharmaceuticals which lead to frequent reordering of products, there is no real idea of the amount of stock in the hospital, the coordination between the needed resources in personnel and the demand for care is difficult to establish because of the lack of information. From a medical point of view, this lack of information system raises two major problems. Firstly, medication errors are not under control. Nurses work most of the time in emergency and are overloaded by administrative tasks. Medication errors that can occur are for instance: wrong dose of medicine, dispensing of a non-prescribed medicine, or oversight of dispensing. Secondly, it makes it difficult to trace pharmaceuticals: it is hard to know which medicine is dispensed to which patient. In addition, the multiple rewritings on different documents (patient's record, pharmaceuticals list and medical ordering forms) are as many chances to make mistakes.
- Troubles in the management of pharmaceuticals: in the care/medico-technical units nurses do a lot of logistical activities linked to the pharmacy like the inventory management of drugs, ordering, use-by date management etc. They are overburdened. Because they are not trained to management, they order drugs when they can in a hazardous manner which causes over stocking and increases the cost of pharmaceuticals. The PAR levels are experience-based defined which lead to overstocking of some products while others are in short supply. These elements induce uncertainties, additional operating costs and lower productivity. Nurses then tend to keep extra stock to not run out, while incurring additional inventory costs and not leading necessarily to better service delivery to the patients (availability of all medicines). Nurses from the medico-technical units and pharmacists take decisions about pharmaceuticals ordering on their own, which makes difficult to set up an inventory management and distribution system for the pharmacy. Emergency orders to suppliers are often placed, at higher costs.
- Troubles in distribution: outbound logistics activities of the clinic pharmacy take a lot of time because of the distance between the units. Several people from the

pharmaceutical staff do the distribution full time. Furthermore, if a drug is in shortage in the care unit, nurses go to the pharmacy and it can take a round of one hour.

These different problems disrupt the working of the care services and solutions should be found that have a positive impact on these problems, to keep the costs under control and to improve the quality of the service provided by the hospital. Therefore there is a need to assess the solutions before their implementation to be sure that they will contribute to the improvement of the performance of the company. The performance is evaluated through measures that are defined according to the objectives of the hospital.

2.2.2 Objectives definition, responsibilities identification and actions to undertake

The approach we led so far has helped us to gain more insight into the working of the medicines dispensing process and into the interactions between the care units and the medico-technical units but we don't know yet how to assess the current system, on basis of which performance indicators. These metrics will give us the information needed to pilot the system, to know if the objectives are achieved and if not, to take the necessary corrective actions. However, prior to the definition of these indicators, we need to define the objectives.

To achieve this difficult task, we base ourselves on the literature review we made and on a particular consulting study undergone for the hospital with which we are working (Antares-Consulting 2004). This consulting company led a strategic study to clarify the hospital strategy and provide the objectives at different decision levels. Both sources give us the common outcome measures. However, the performance drivers that reflect the uniqueness of a particular hospital working, how the outcomes are to be achieved, are defined based on our knowledge of the current system.

The **Figure 28**, on the next page, represents the objectives table. At the first level, we have the strategic objectives, at the second level, the tactical objectives and at the third level, the operational objectives. The level 4 defines the particularities of the hospital, for each care unit. We will now detail how we translate the objectives of the level 3 into objectives of the level 4 using the connectance diagrams.

For each objective at level 3, we identify what are the different resources aspects and the different variables. The identified variables for the objectives at level 3 are the basis for the objectives definition at level 4. The actions to undertake are the possible solutions that can be adopted to influence in positive way the objectives at level 3. We then identify for each objective the different processes and activities involved and the responsibilities are pointed up. This task is realized thanks to the information we gather about the hospital working through the logical diagrams.

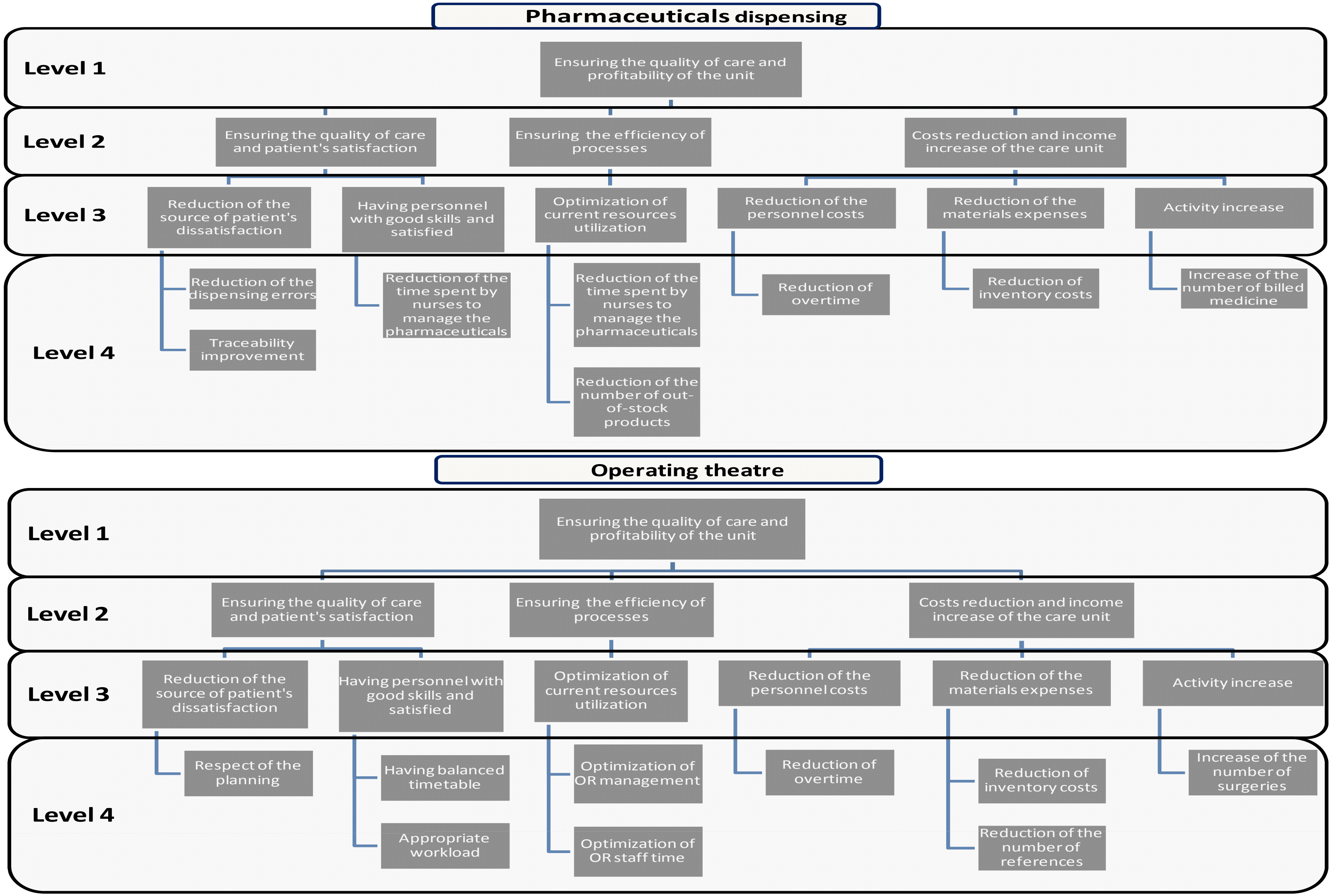

Figure 28. Translation of the strategy into objectives at the different decision level

a. Ensuring the quality of care and the patient's satisfaction

The objective of the hospital's activity is to provide care to the patients and to meet their requirements in terms of quality. As in most service activity, the personnel in direct contact with the client plays an important role in the patient's quality perception. The achievement of that objective at a tactical level is translated at the operational level by focusing on the patient's perception of care (to ensure patient's satisfaction) and by focusing on the personnel providing the care.

♦ *Reduction of the source of the patient's dissatisfaction*

Concerning the pharmaceuticals dispensing activities, its aim is to provide the care with a quality support. It has "to deliver the right dose of the right medications to the right patients at the right time through the right route" (Mazur et al. 2007). The patient is concerned by receiving the appropriate medicines under safety conditions. Therefore the medical dispensing error has to be minimized and the traceability guaranteed.

Dispensing errors are mistakes that occur in the dispensing of pharmaceuticals to the patients. Meier (Meier 2001) identifies 3 main types of dispensing errors in the dispensing process: dispensing of the wrong products, dispensing of the wrong dose or non-dispensing of the products. These errors can put in danger the patient's live and therefore have to be reduced or erased. It occurs mainly during two activities: the preparation of the medicines (to make) and their delivery (to dispense).

The Figure 29 represents the connectance diagram of the objective "reduction of the source of patients'dissatisfaction" for the pharmaceuticals dispensing. There are three aspects of this objective: the system, the labor and the process. The system refers to the infrastructure that is used to register the patient's information. The labor makes reference to the nurses who are recording the information for the patients. The process refers to how the information is registered. To increase the efficiency of the process, the simplification of the process or the setup of more control could help to improve the number of patient's recorded files. To do so, the setup of an information system could lead to this simplification (fewer activities) and to a better control. This system could also lead to an automation of the system through scanning that would improve the system working. By providing the nurses with the appropriate training and adding more control, the traceability of the medicine could be improved. The identified variables, automation, training, control, traceability and simplification will serve to define the particular objectives for the hospital of our concern.

From the OT point of view, all activities where the patients are involved, basically all care activities, could influence the quality perceived by the patient. We are however in this study more interested in the processes/activities that can influence negatively the patient's satisfaction due to dysfunctions in the process. The patient is given an admission day based on the forecast day of the surgery and is not willing to wait for the surgery. Therefore, the planning respect is important. We thus focus more on the OT management that could trigger delays in the planning and so, causes patient's dissatisfaction.

For the OR, the management has to stay as close as possible to the planning to respect the programmed day of the elective surgeries and to provide at the same time enough flexibility to take care of the emergency surgeries. Therefore a tool to determine a feasible planning could help. The Table 7 presents the objectives, activities, responsibilities (between brackets) and the involved processes.

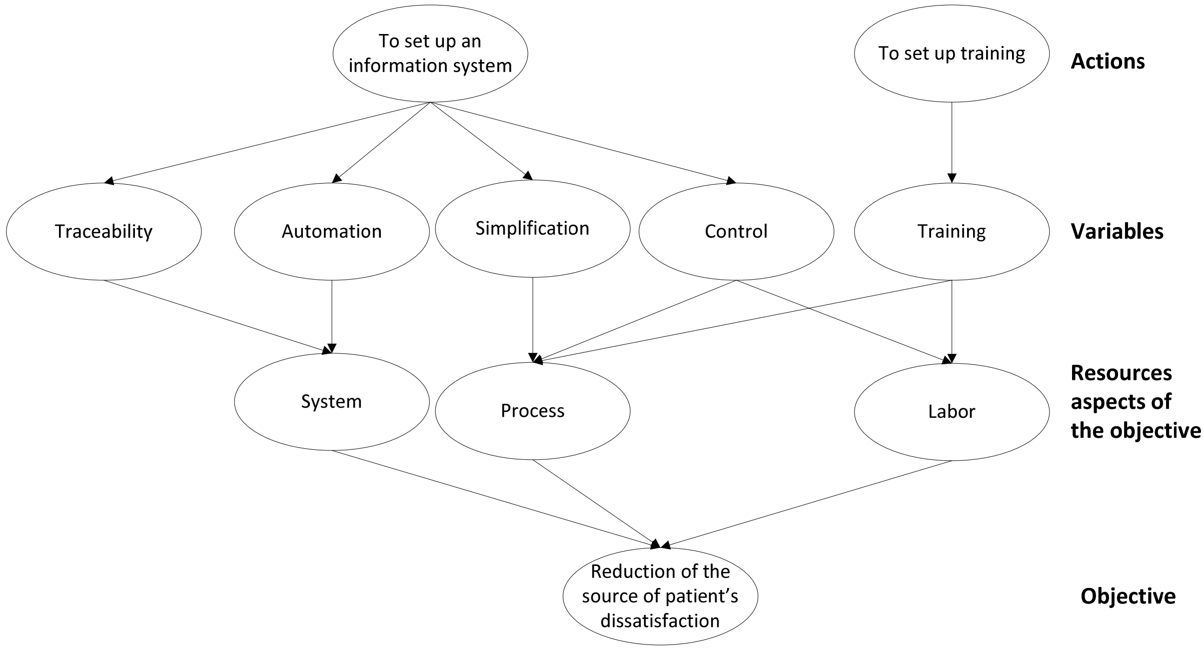

Figure 29. Connectance diagram for the objective "reduction of the source of patient's dissatisfaction"

Table 7. Activities and processes identification for the objectives of quality of care and patient's satisfaction

	Objectives	*Process*	*Activities (responsibilities)*
Ph.Disp[7]	Reduction of the dispensing errors	Pharmaceuticals dispensing process	To dispense (Nurses)
	Reduction of the dispensing errors	Pharmaceuticals dispensing process	To make (Nurses)
	Traceability improvement	Pharmaceuticals dispensing process	To fill in the patient's records (Nurses)
	Traceability improvement	Pharmaceuticals billing process	To fill in the pharmaceuticals list (Nurses)
	Implementation of an information system		Project
	Training of nurses		Project
OR	Respect of the planning	OT management decisions – level 2	Elective surgeries planning (nurses)
	Respect of the planning	OT management decisions – level 3	Emergency and elective surgeries scheduling

[7] Ph. Disp : pharmaceuticals dispensing

	(nurses)

♦ ***Having personnel with good skills and satisfied***

The delivery of a quality service to the patients is relying upon qualified personnel who are able to provide the patients with a care of quality under safety conditions. The objective aims also to develop communication and team working abilities and to ensure the coherence and coordination of training process for newly hired people.

What about the personnel satisfaction, it has more to do with the planning and working hours of the nurses. In term of pharmaceuticals dispensing, the suppression of non value added activities for care can light the work charges of the nurses; in our case, it is linked to activities related to the management of pharmaceuticals that don't require medical skills. . The setup of an automated system can free the nurses of the billing charge.

For the OT, it has to do with the building of balanced time table and appropriate workload (good balance between overtime and non worked hours). This is part of the human resources management.

The Figure 30 illustrates the network diagram from the TAPS methodology we use to identify the actions to undertake to meet the objective at level 3, having personnel with good skills and satisfied. To have skilled and satisfied personnel, the management should consider the setup of appropriate training so that the nurses are more polyvalent and get less stress from the work. The reduction of overtime and the building of feasible schedule should also help to reduce the work burden and provide the nurses with a better work environment. It can be done through an optimization model that takes into account personnel to establish the planning and scheduling of the OR.

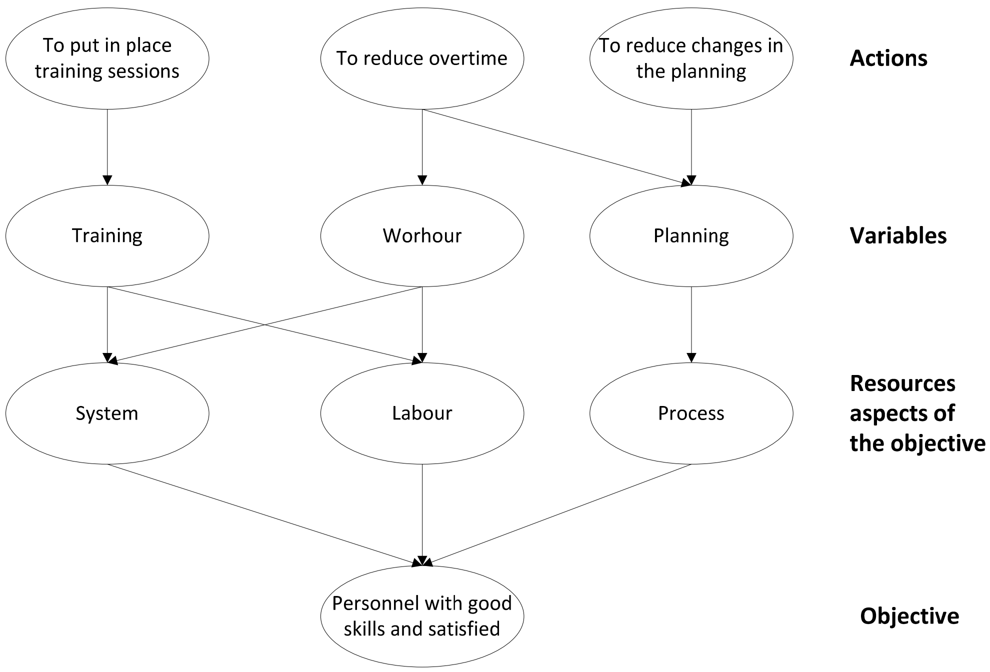

Figure 30. Connectance diagram for the objective "personnel with good skills and satisfied"

Table 8. Activities and processes identification for the objectives of ensuring efficient processes

	Objectives	*Activities (responsibilities)*	*Process*
PhDisp	Reduction of the time spent by nurses to manage the pharmaceuticals	To fill in the pharmaceuticals list (Nurses)	Pharmaceuticals billing process
OT	Having balanced timetable	Monthly time tabling for nurses (nurses)	OT management decisions – level 1
	Appropriate workload	Allocation of nurses to the OR (nurses)	OT management decisions – level 2
	Appropriate workload	Allocation of nurses for emergency surgeries (nurses)	OT management decisions – level 3

b. Ensuring the efficiency of the processes

An efficient process can be defined as the ability to provide the desired outcome while minimizing the resources consumption. That means to optimize the current working of the system and to try to reduce the non value added activities.

♦ *Optimization of the current resources utilization*

For the pharmaceuticals dispensing, the optimization of resources is focused on the reduction of the time spend by nurses to do non value added activities, as the time spend to order the pharmaceuticals. An efficient process for the pharmaceuticals dispensing means also to have the right product available at the right time and so to minimize the number of products out-of-stock.

The review of the inventory management policy to determine the products to keep in stock and the PAR level should help to reduce the number of products out-of-stock. The automated system also allows ordering automatically and thus reduces the time spent by nurses to manage the pharmaceuticals through the use of the bar codes and the integrated information system.

For the OT, the most constrained resources are the number of OR that require huge investment and the nurses who are most of the time outnumbered and under constraining legislation about working hours. The surgeons and the anesthetists are not considered since they are in most Belgian hospitals self-employed.

The optimization of the OR time means to better use the OT time to have less inactivity time during the normal hours and to increase the number of surgical interventions without overtime. That means also to better manage the block time scheduling to the different specialties. For the nurses, it means to reduce the inactivity time for the nurses. The Figure

31 illustrates the connectance diagram we use as an example in the chapter 3. A good planning tool is therefore needed.

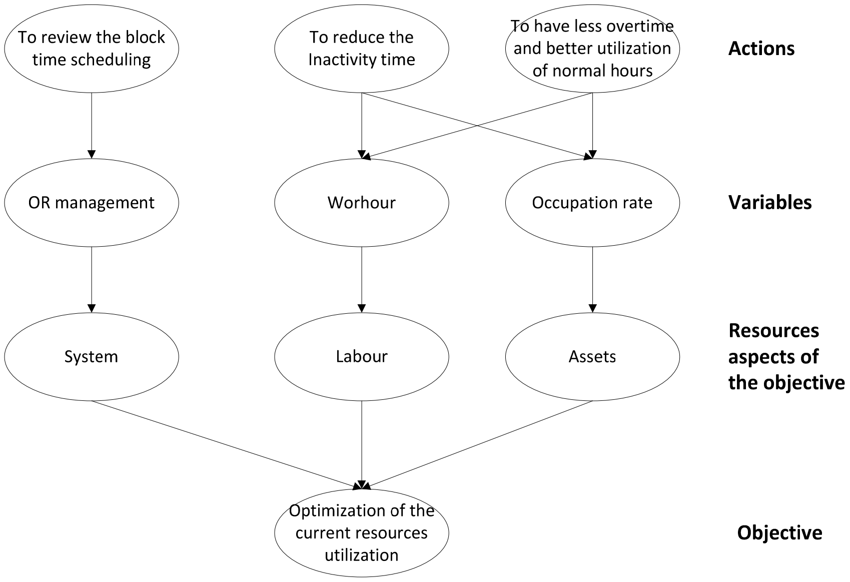

Figure 31. Connectance diagram for "optimization of the current resources utilization" for the OR

Table 9. Activities and processes identification for the objectives of optimizing the utilization of resources

	Objectives	*Activities (responsibilities)*	*Process*
Ph.Disp	Reduction of the time spent by nurses to manage the pharmaceuticals	To sort the pharmaceuticals (Nurses)	Pharmaceuticals ordering process
	Reduction of the time spent by nurses to manage the pharmaceuticals	To fill in the patient's record (Nurses)	Pharmaceuticals ordering process
	Reduction of the number of out-of-stock products	To order (when the medicines are not on the shelves)	To reduce the number of out-of-stock products
OT	Optimization of OR management	OR planning (nurses)	OT management decisions: level 1, level 2 and level 3
	Optimization of OR staff time	HR management (OR head nurses)	OT management decisions: level 1, level 2 and level 3

c. Costs reduction and income increase of the care unit

The pharmaceuticals dispensing is under the responsibility of the clinic pharmacy that is the third revenue provider of the hospital. The revenue of that medico-technical is mainly based on the "selling" of pharmaceuticals products to the patients. The accuracy of the billing is thus important to ensure minimal revenue.

The OT is an important cost center of the hospital. Its revenue is based on the number of surgical procedures that are led. It is needed to manage it properly to increase the income.

♦ *Reduction of the personnel costs*

The reduction of the personnel costs doesn't mean necessarily a downsizing. In the case of the hospital where the shortage of nurses is sometimes important, it essentially means to reduce the overtime that are expensive worked hours.

To reduce overtime, the building of appropriate schedules that minimize overtime and non worked hours is important.

Table 10. Activities and processes identification for the objective of reducing the personnel costs

	Objectives	*Activities (responsibilities)*	*Process*
OT	Reduction of personnel costs	HR management (OR head nurse)	OT management – Level 1

♦ *Reduction of the materials expenses*

In terms of pharmaceuticals dispensing, the expenses in the materials are the costs incurred by the inventory management policy as the holding costs and the backorder costs of emergency orderings.

The costs of materials in the OT are currently important due to the amount and variety of products kept on storage as the holding costs and the costs of emergency ordering. The reduction of materials expenses could be reached through a review of the inventory management policy to decrease the quantities kept in stock and to reduce the number of products that are out-of-stock and through a standardization of the preference lists used by the surgeons to reduce the number of references kept in stock.

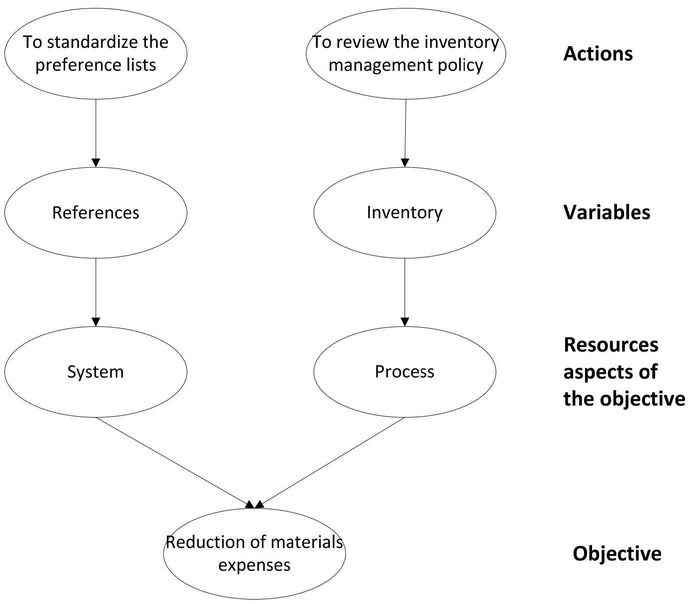

Figure 32. Connectance for the objective of "reduction of materials expenses" – Operating rooms

Table 11. Activities and processes identification for the objectives of reducing the materials expenses

	Objectives	*Activities (responsibilities)*	*Process*
Ph. Disp	Reduction of inventory costs	To order (when the medicines are not on the shelves) (nurses)	Pharmaceuticals ordering process
OT	Reduction of inventory costs	To determine PAR level (OR head nurse)	Materials management level 2
	Reduction of inventory costs	To order (nurses)	Materials management level 3
	Reduction of the number of references	To choose the surgery tools (surgeons)	Materials management level 2

- ***Activity increase***

The clinic pharmacy is a cost center that incurs operating expenses and that has to bill the products to be delivered. One of the operating expenses is the cost of pharmaceuticals supplied and the revenue is based on the products billed to the patients. The setup of the information system linked to the automated system will increase the control and ensure that each time a medicine is taken in the board it is registered in the patient record and billed to the patient.

The increase of the number of surgeries could be reached through a clear surgical offer and the right number of surgeons with the adequate skills to meet the demand. The reduction of unused block time (reduction of inactivity time) would allow leading more surgical interventions without increasing the personnel costs.

Table 12. Activities and processes identification for the objectives of increasing activity

	Objectives	*Activities (responsibilities)*	*Process*
Ph. Disp	Increase of the number of billed medicine	To fill in the patient's record(Nurses)	Pharmaceuticals dispensing process
OT	Increase of the number of surgeries	Elective surgery planning (OR manager)	OT management decisions – level 2

2.3 Building the scorecard

2.3.1 Strategic map

After having translated the strategy into the objectives at the different decisions level, we now link the objectives with the different axes of the balanced scorecard.

The objectives are organized in four perspectives: finance, clients (the patients), internal processes and learning and growth. The different perspectives are linked by a cause and effect reasoning. The objectives are defined in a way to ensure coherence in the actions taken to reach the stated mission.

The Figure 33 describes the strategic map we build for the pharmaceuticals dispensing system. We use a IF-THEN logic to link the different objectives.

For instance, IF the number of products that are out-of-stock is reduced, THEN it will reduce the costs of emergency ordering and so the total costs of inventory. IF the costs of emergency ordering are reduced THEN the profitability of the pharmacy will increase. IF the traceability of the pharmaceuticals is improved THEN the service quality delivered to the patients will increase. This will also increase the billed medicines and so, increase the financial income.

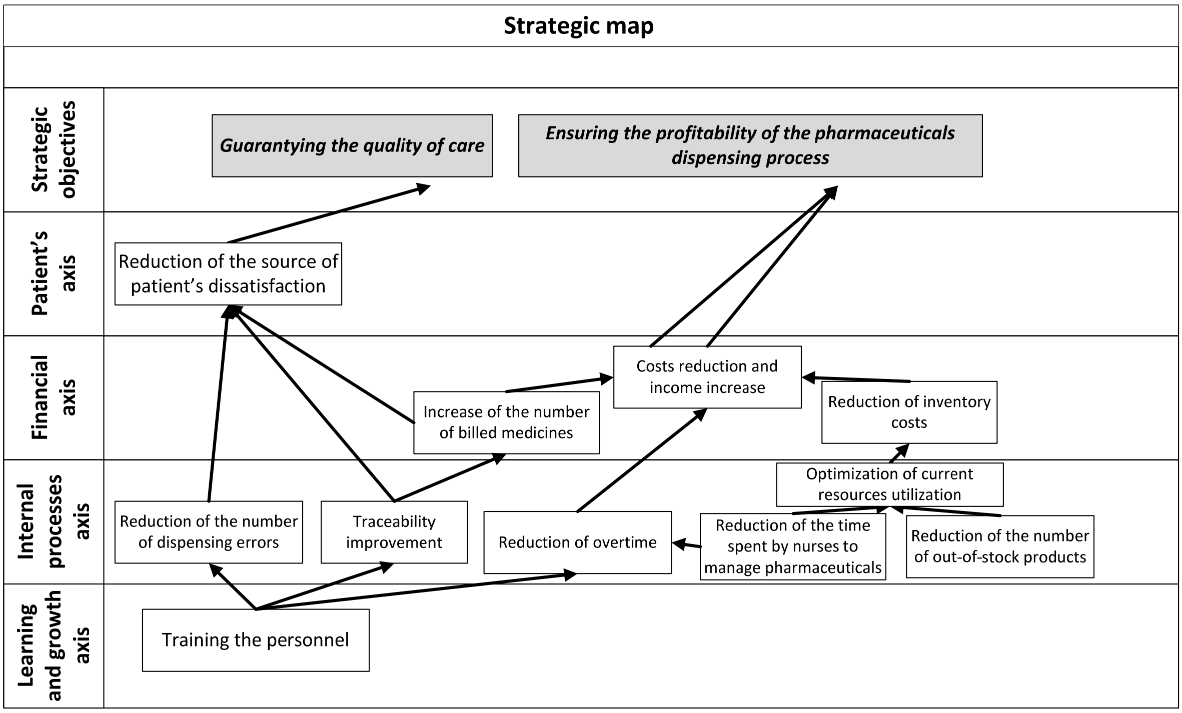

Figure 33. Strategic map for the pharmaceuticals dispensing

The Figure 34 describes the strategic map for the OT. For instance, an increase in the quality of care can improve the hospital image and so increase the surgical activity. If there are more surgeries, and if the other variables stay good, it will increase the income of the operating theatre which will positively contribute to its profitability.

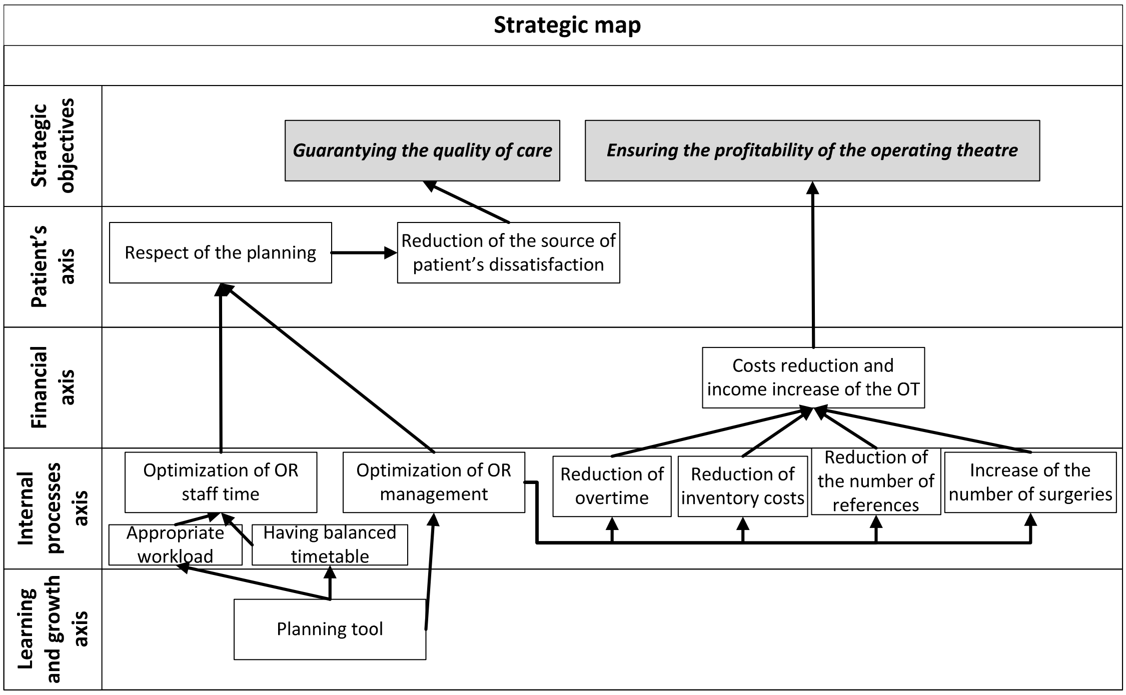

Figure 34. Strategic map for the OT

2.3.2 Identification of performance indicators

To identify the different indicators, the literature about the hospital management has been reviewed to identify possible performance indicators. The list of the different indicators has been submitted to the actors of the hospital and has been validated. The survey was submitted to the personnel of the OR. They were asked to cote the indicators up to 10, 10 being for a relevant indicator (depending on the importance they give to the indicators). The Table 13 presents the results of this survey.

Table 13. List of indicators for the OT

Indicators of satisfaction	***Indicators of quantification***
Number of patients' complaints	
Patient's satisfaction rate	Number of cared patients
Patient's complaints rate	
Activity indicators	***Outcome indicators***
	OR occupancy rate
Number of surgeries for outpatients	OR inactivity rate
Total number of surgical procedures	Surgical intervention delay rate
Surgical intervention time	Block time overtime
Inactivity hours	Emergency surgeries rate
	Outpatient rate
	Elective surgeries rate
Quality indicators	***Motivation indicators***
Number of people in the OR	Personnel satisfaction rate
	Skilled personnel rate
	Turnover
Cost indicators	***Financial indicators***
Total costs	Profitability
	Income

2.3.3 Indicators linked to the different axes

We now link the different indicators to the objectives. A same indicator can measure the achievement of several objectives.

a. The patient's perspective

The hospital has as objective to provide a quality service to meet the patients' expectations. The measurements of the service quality are subjective and are dependent on the patients. It can be estimated through a survey.

Table 14. Indicators linked to the patient's perspective – pharmaceuticals dispensing

Level	*Objectives*	*Indicators*	*Definitions*
2	Ensuring the patient's satisfaction	Number of unsatisfied patients	Number of patients who complaint
4	Reduction of the dispensing errors	Number of dispensing errors	Number of products that were inappropriately dispensed
4	Traceability improvement	% of non recorded pharmaceuticals	nb of dispensed pharma not recorded in the patient's file/nb of consumed pharma
4	Traceability improvement	% of misrecorded pharmaceuticals	nb of pharma recorded in the patient's file but not on the pharma list/nb of consumed pharma

The main goal of the OT is to provide the patient with a quality service.

Table 15. Indicators linked to the patient's perspective – operating theatre

Level	*Objectives*	*Indicators*	*Definitions*
2	Ensuring the patient's satisfaction	Number of patients	Number of patients who underwent surgery over a determined period
2	Ensuring the patient's satisfaction	Patient's satisfaction rate	Ratio between the number of patients satisfied by the service received and the total number of patients
2	Ensuring the patient's satisfaction	Patient's complaints rate	Ratio between the number of complaints and the total number of patients
4	Respect of the planning	Number of cancelled surgeries	Number of surgeries that were cancelled because not planned within x days

b. The financial perspective

While putting in place the new automated dispensing cabinet, the hospital wants to increase the profitability of the pharmacy. Two objectives are to be followed:

- The reduction of the operating expenses: to reduce the costs of inventory management, that means to reduce the holding costs and backorder costs.
- The increase of the revenue: as already explained, the revenue of the pharmacy mainly comes from the pharmaceuticals billing. The pharmacy has thus to increase the proportion of pharmaceuticals that are invoiced to the patients and to ensure that the new project is profitable.

Table 16. Indicators linked to the finance perspective – pharmaceuticals dispensing

Level	*Objectives*	*Indicators*	*Definitions*
2	Costs reduction and income increase of the care unit	Total operating costs	Operating costs of the pharmacy
4	Reduction of inventory costs	Total holding costs	Cost of holding the pharmaceuticals in the ER
4	Reduction of inventory costs	Total backorder costs	Cost of ordering the pharmaceuticals in emergency
4	Increase of the number of billed medicine	Income	Income generated by the billed pharmaceuticals
4	Increase of the number of billed medicine	pharmaceuticals billing rate	1-(% non recorded pharma + % misrecorded pharma)

Even if the OT is one of the most important cost center of the hospital, its first objective is not to make profit. The costs should stay under control and thus the main costs factor are to be tracked, the personnel and the materials.

Table 17. Indicators linked to the finance perspective – operating theatre

Level	*Objectives*	*Indicators*	*Definitions*
2	Costs reduction and income increase of the care unit – OT	Profitability	Ratio between the profit generated by the surgical activity and the total expenses
2	Costs reduction and income increase of the care unit – OT	Costs	Costs linked to the OT activity
4	Increase of the number of surgeries	Revenue	Income generated by the surgical activity
4	Reduction of overtime	Personnel expenses	Costs of personnel
4	Reduction of inventory costs	Inventory cost	Costs of inventory (holding costs and backorders costs)
4	Reduction of the number of references	Number of references	Number of different items in the preference lists

c. *The internal processes perspective*

The internal processes perspective focuses on the key processes and activities that will help the hospital to achieve the objectives defined in the patient and the financial perspective:

- The improvement of the traceability would lead to a reduction in the dispensing errors and will increase the billing rate.
- The reduction of the time spent by nurses for administrative purpose will lead to a reduction in the dispensing errors.
- The patient is concerned with the quality of care; he wants to receive the best care possible and the right medicine. The reduction of the number of dispensing errors can increase the patient's satisfaction.
- The patient also wants to receive the best treatment as soon as possible, especially in the emergency rooms. The patient is therefore concerned about the availability at the ER of the pharmaceuticals. Having the medicine available at the ER is thus another objective.
- The patient is also concerned with the bill he will receive and with its accuracy. The right pharmaceuticals have to be invoiced. It is therefore important to improve the accuracy of the billing.

Table 18. Indicators linked to the internal processes perspective – pharmaceutical dispensing

Level	*Objectives*	*Indicators*	*Definitions*
4	Reduction of the time spent by nurses to manage the pharma	% time spent by nurses to fill in the patient's file	Time spend to fill in the file/total working time
4	Reduction of the time spent by nurses to manage the pharma	% time spent by nurses to order the pharmaceuticals	Time spend to order the pharmaceuticals/total working time
4	Traceability improvement	% of non recorded pharmaceuticals	nb of dispensed pharma not recorded in the patient's file/nb of consumed pharma
4	Traceability improvement	% of misrecorded pharmaceuticals	nb of pharma recorded in the patient's file but not on the pharma list/nb of consumed pharma
4	Reduction of the number of out-of-stock products	number of out-of-stock products	nb of out of stock during a cycle (30 days)
4	Reduction of the dispensing errors	% of errors due to the wrong amount of medicine dispensed	nb of pharma dispensed in the inappropriate qty/ total nb of pharma dispensed
4	Reduction of the dispensing errors	% of errors due to the wrong product dispensing	nb of pharma dispensed inappropriately/total nb of pharma dispensed
4	Reduction of the dispensing errors	% of errors due to the non dispensing of the prescribed drug	nb of non dispensed pharma/ total nb of pharma
4	Increase of the number of billed medicine	% of misrecorded pharmaceuticals	(nb of pharma recorded in the patient file and not on the pharma list)/nb of consumed pharma

For the operating rooms, the objectives are to optimize the OR time allocation and staff time to reduce the inactivity and to reduce the overtime.

Table 19. Indicators linked to the internal processes perspective – operating theatre

Level	*Objectives*	*Indicators*	*Definition*
2	Ensuring the efficiency of processes	Delay hours	Total delay hours for elective surgeries
2	Ensuring the efficiency of processes	Overtime	Total hours during which there were surgeries after the normal closing hours (16H00)
2	Ensuring the efficiency of processes	Delay rate	Delay hours/total opening hours
2	Ensuring the efficiency of processes	Overtime rate	Overtime/total opening hours (in normal hours)
4	Optimization of OR management	Occupation rate	Activity hours/total opening hours (in normal hours)
4	Optimization of OR management	Inactivity rate	Inactivity hours/total opening hours (in normal hours)
4	Optimization of OR management	Activity hours	Total number of hours used by elective surgeries
4	Optimization of OR management	Inactivity hours	Total number of hours where the ORs are open but during which there is no activity
4	Increase of the number of surgeries	Number of surgical procedures	
4	Increase of the number of surgeries	Elective surgery rate	Activity hours/total operating time
4	Increase of the number of surgeries	Emergency surgery rate	Total time required by emergency surgeries/total operating time
4	Increase of the number of surgeries	Ambulatory surgery rate	
4	Optimization of OR staff time	Overtime	Total hours during which there were surgeries after the normal closing hours (16H00)

d. The learning and growth perspective

The objectives of the learning and growth perspective are linked to the means and factors that have an influence on the way to reach the objectives defined in the 3 other perspectives.

For the pharmaceuticals dispensing, we identified 3 actions that can positively affect the objectives.

- The setup of the automated dispensing cabinet.

- The implementation of an information system (comes along with the dispensing cabinet).
- The training of nurses.

The indicators are binary: the actions are taken or not.

Table 20. Indicators linked to the learning and growth perspective – pharmaceutical dispensing

Objectives	*Indicators*
Implementation of an inventory management system	Yes/No
Implementation of an information system	Yes/No
Training of nurses	Yes/No

Concerning the OT, one of the main objectives is to put in place a planning tool.

Table 21. Indicators linked to the learning and growth perspective – operating theatre

Level	*Objectives*	*Indicators*	*Definition*
2	Having personnel with good skills and satisfied	Personnel satisfaction rate	Ratio between the number of employees satisfied by the current working organization and the total number of employees
2	Having personnel with good skills and satisfied	Personnel turnover	Ratio between the total number of employees who left during the year and the total number of employees.
2	Having a personnel with adequate skills	Skilled personnel rate	Ratio between the number of employees who have received training and the total number of employees
4	Appropriate workload	Overtime	Total hours during which there were surgeries after the normal closing hours (16H00)

2.3.4 Challenges in building the scorecard

Scorecards have been so far widely implemented in the industry. The building of a scorecard is however not easy and some problems are commonly listed (Oliviera 2001; Pink et al. 2001), as the difficulty to get data and to provide the balanced scorecard with, the problems to validate the information gathered and to ensure their accuracy. The setup of a scorecard itself depends upon the commitment of the management to get the right insight into the working of the system. The elaboration of a scorecard for a hospital doesn't fail to these difficulties. In addition to these challenges, the value proposition of the customer perspective is particularly difficult to define (Inamdar et al. 2002; Oliviera 2001; Pink et al.

2001). The different stakeholders (payers, patients, regulators and physicians) have indeed their own value proposition in term of access, quality, cost and choice. These propositions can be conflicting and it is not easy for the management to communicate about the strategy (Inamdar et al. 2002). In addition, in the healthcare sector, the focus is more on the customer and it is difficult to measure his satisfaction.

We can also notice that the balanced scorecard suggests a cause and effect logic to define the indicators. There are numerous interactions between the different processes, which makes difficult to use that cause and effect logic. In addition, the balanced scorecard doesn't provide a tool link the indicators to the processes.

2.4 Conclusion

The knowledge modeling helps us to gain more understanding into the working of the pharmaceuticals dispensing system and into the working of the medico-technical units of our concern, the ER and OT. The application of the Porter's value chain highlights the numerous links existing between the care units and the clinic pharmacy and emphasizes one more time the need to carefully evaluate the changes in the pharmaceuticals dispensing before implementing them. The logical diagrams fill in our knowledge of the system working and identify the different responsibilities. At that point, we could point up a number of weaknesses in the current organization of the medicine dispensing: the redundancy of activities, the poor integration of the information system, the current management of pharmaceuticals that lead to overstocking and out-of-stock products and the troubles in distribution. These weaknesses have both financial and cost impacts.

Before proposing solutions and implementing them, the current situation has to be quantified by indicators. That supposes that the objectives are already defined. Starting from the literature review and from a consulting study, we highlight the general objectives, which give the general outcome measures. We use the connectance diagrams and the knowledge acquired through the logical diagrams to determine the specific objectives for the units, the performance drivers for the OT and for the ER. The strategy map helps us to ensure that the objectives are taking into account the different stakeholders perspectives and that the different objectives provide a tool to the management to pilot the hospital towards the achievement of the strategy.

At the same time, we also identify what are the actions to undertake to reach the objectives. Concerning the pharmaceuticals dispensing process, we determine that the setup of an automated dispensing cabinet could bring a solution to the problems of traceability, inventory management, information system and distribution. Concerning the OR, the knowledge modeling points out that the dispensing process was highly dependent upon the OR planning and scheduling. The quality of the service to the patients is highly dependent upon that aspect. Therefore, there is a need to focus on the planning part. However, these solutions have to be evaluated and compared to the current situation before their implementation.

Chapter 5. Actions models

1 *The setup of the automated dispensing system*

To solve the problem of the pharmaceuticals dispensing process, the hospital management wants to set up an automated dispensing system. This system could give a solution to the problem we identified in the previous chapter: it is an automated system that could bring more control in the system; it is an informatics information system and if controlled by an appropriate inventory management policy, it could bring potential savings. However, before being implemented, the potential solution has to be evaluated on some of the indicators we identified during the knowledge building phase. At the time we made our study, the automated cabinet was not yet implemented in the test department, the ER. This project is still undergoing today because of the lack of resources, human and financial. We therefore had to base ourselves on some studies made in other hospitals about the implementation of such a cabinet to assess the potential gains of the project.

We will now study the implementation of the proposed solution (Di Martinelly et al. 2007a). We briefly describe this system and justify the choice of that implementation by considering two points of view, a security one and a process one. The medical viewpoint considers the mistakes that could be done by nurses and how the automated system could secure the process. The process viewpoint takes into consideration the simplification that could be brought in the pharmaceuticals dispensing.

1.1 Suggested system

The automated dispensing cabinet will be installed in the ER and should be electronically connected to the pharmacy. This type of cabinet is similar to cash dispenser and are designed to store and deliver the pharmaceuticals. The care personal has to sign up through a password. Then the patient data are introduced into the system. Solely the drawers with the medicines dedicated to the patient are opened. The nurses have just to take the right quantity. The Figure 35 shows a standard automated dispensing cabinet as implemented in the hospital.

Figure 35. Pyxis cabinet

1.2 Quality/traceability enhancement

One of the main advantages of a dispensing cabinet is to improve the patient's safety through automation of the process and better traceability of the medicines. In the hospital, any studies were not yet led to evaluate the current dispensing errors or the time spent by nurses to manage the pharmaceuticals. We therefore based ourselves on medical studies undertaken in other hospitals that estimate the impact of the implementation of the automated dispensing cabinet on the quality of care.

The first two studies (Du Pasquier et al. 2003; Meier 2001) were led in a Swiss university hospital. An experimental pharmacy was set up and a standard stock was created in an empty ward. Voluntary nurses were enrolled in the project. They were asked to prepare and distribute the doses for 20 patients, once without the dispensing cabinet and once with it. The results from the studies are shown in the Table 22. These studies were undertaken in an experimental environment, which, according to the authors, largely leads to underestimate the number of errors.

The other study we took under account was led in a 1000 beds hospital, the Riverside Methodist Hospital in Columbus (Lee et al. 1992). This hospital implemented the automated dispensing cabinet in 2 care units and evaluated the time spent by nurses form medication-related activities and documentation. They also evaluated the billing rate. 2900 observations were considered.

Table 22. Impact of the introduction of the automated cabinet in 2 other hospitals (Du Pasquier et al. 2003; Meier 2001)

	Value of the indicators before the introduction of the automated cabinet	*Value of the indicators after the introduction of the automated cabinet*
Objective: reduction of the dispensing errors		
% of errors due to the wrong amount of medicine dispensed	0,6%	0,2%
% of errors due to the wrong product dispensing	2,2%	0,1%
% of errors due to the non dispensing of the prescribed drug	0,2%	0,1%
% of reduction of the dispensing errors (total)	3%	0,4%
Objective: reduction of the time spent by nurses to manage the pharmaceuticals		
% time spent by nurses to fill in patient file	28%	16,9%
% time spent by nurses to order pharmaceuticals	10,20%	5,6%
% of time to manage the pharmaceuticals (total)	38,2%	22,5%
Billing rate	63%	97%

These studies provided us with an estimation of the potential benefits of the system setup in the ER. The introduction of the automated dispensing cabinet reduces the administrative tasks of the nurses by 15,7% (38,2% - 22,5%) which corresponds to approximately 1 hour saved each 8 hours working day. This spare time could therefore be devoted to other tasks. In addition, the medication errors are also reduced. The percentage seems tiny but it is patient-life related and any saving is considered as important.

1.3 Simplification of the processes

The setup of this new system will impact the dispensing process. It is needed to know what the process changes in the hospital are. The introduction of the automated dispensing cabinet will impact the three operational processes we described on page 95, namely the pharmaceuticals dispensing in the care unit, the billing process and the pharmaceuticals ordering process, and will greatly simplify the process through automation. The changes are indicated on the logical diagrams to show them understandably:

- The pharmaceuticals dispensing process: the nurses won't have any more to fill in the patient's record with the consumption or to recopy on the pharmaceuticals list.
- The pharmaceuticals billing process: the billing process will be automatic.

- The pharmaceuticals ordering process: the ordering process of each period will be automatic and at the end of cycle, someone from the pharmacy will check the PAR level and fill them if needed.

The biggest change from the implementation of this automated cabinet will be on the billing process. As we underlined it in the chapter 4, the pharmacy is the third revenue provider of the hospital through the pharmaceuticals billed to the patients. Some weaknesses were identified in the process as:

- Non-recorded pharmaceuticals.
- Pharmaceuticals booked in the patient's record but not on the pharmaceuticals list.
- Pharmaceuticals booked on the pharmaceuticals list but improperly recorded on the patient's invoice.

These weaknesses cause a financial loss for the hospital that we want to quantify. To evaluate the financial loss, we led a study in the emergency room. This study went into two parts: a stocktaking study was done at the beginning and at the end of the period to evaluate the pharmaceuticals consumption; over the same period, the different documents related to the pharmaceuticals dispensing process (patient's records, pharmaceuticals list and bills) were checked to track the pharmaceuticals. The period considered for the study is 10 days in February 2005. The patient's bills were checked over a longer period to be sure to track all the patients' bills. A total of 276 patients were admitted in the ER over that period and more than 700 files were verified.

The comparison between the pharmaceuticals consumed and the pharmaceuticals billed to the patients gives us the loss over a 10-day period. The pharmaceuticals are valued to their selling price to the patients. The Table 23 displays these results.

Table 23. Pharmaceuticals consumption and billing over a period of 10 days (February 2005)

	Value
Pharmaceuticals dispensed to the patients	4.735,00 €
Pharmaceuticals booked on the pharmaceuticals list	2.868,76 €
Pharmaceuticals booked in the patient's record	850,86 €
Pharmaceuticals effectively billed to the patients	2.139,64 €

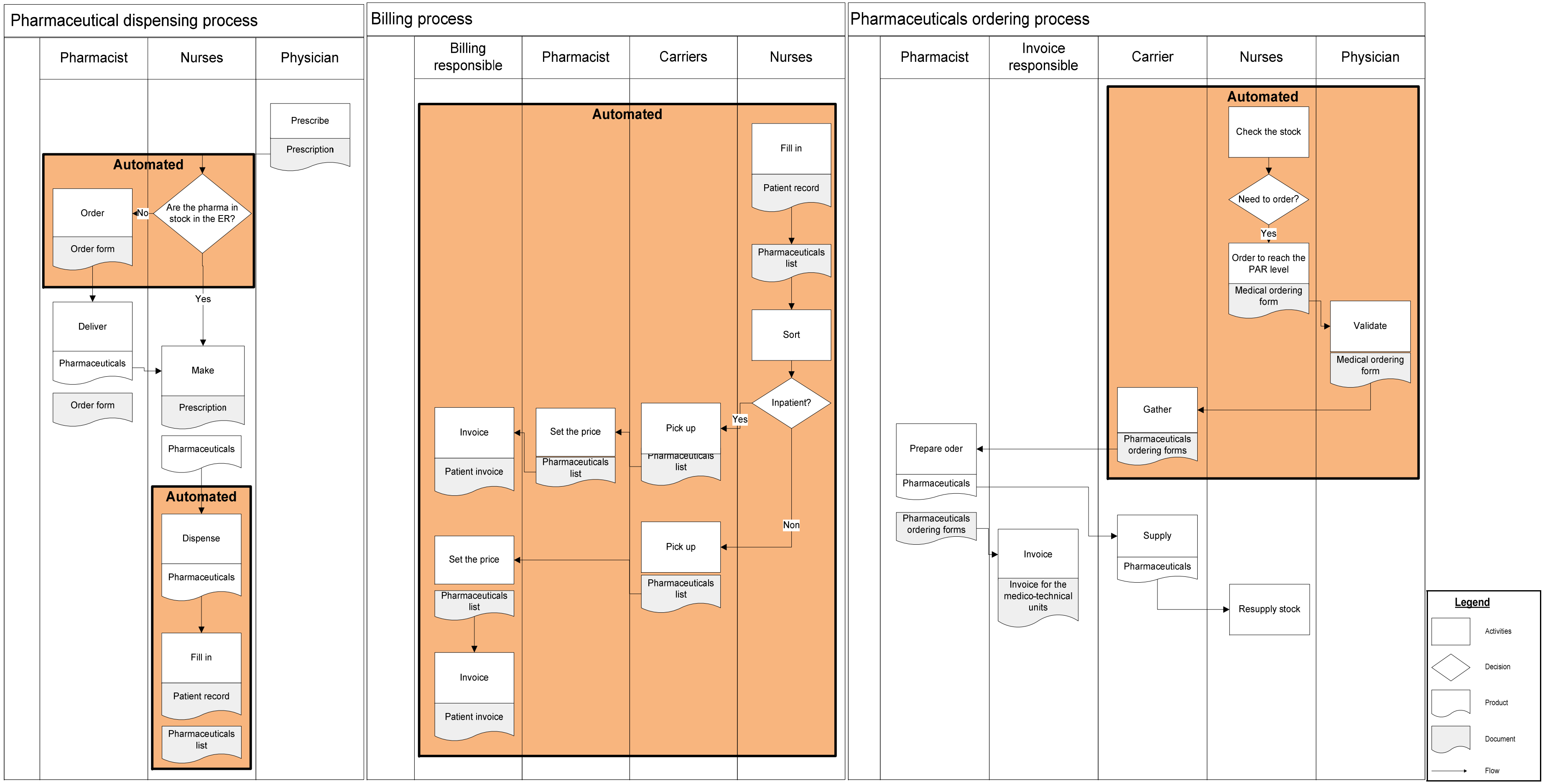

Figure 36. Changes introduced by the automated dispensing cabinet

Thanks to this study, we could estimate the indicators identified in the chapter 4 and that are presented in the following table.

Table 24. Actual performance of the system

	Value
Objective : Increase of the number of billed medicines	
pharmaceuticals billing rate	45,19%
Objective : Traceability improvement of the pharmacy	
% of non recorded pharmaceuticals	39,41%
% of misrecorded pharmaceuticals	15,40%

Because the automated dispensing system is not yet set up, we couldn't get the actual savings. We decided to evaluate the expected gains while basing ourselves on the study led by (Lee et al. 1992) and that estimated a billing rate of 97% after implementation of the cabinet. The results of this study are presented in the Table 25.

Table 25. Value obtained after the implementation in another hospital

	Value
Objective : Increase of the number of billed medicines	
pharmaceuticals billing rate	97%
Objective : Traceability improvement of the pharmacy	
% of non recorded pharmaceuticals	2%
% of misrecorded pharmaceuticals	1%

We base ourselves on these values to evaluate the expected gains we could get from the setup of the automated dispensing cabinet (Table 26).

Table 26. Expected gains from the implementation of the automated dispensing cabinet in the hospital

	Value (AS-IS)	*Value (TO-BE)*
Pharmaceuticals booked in the patient's record	850 €	4687 €
Pharmaceuticals booked on the pharmaceuticals list	2868 €	4640 €
Pharmaceuticals effectively billed to the patients	2139 €	4592 €
Pharmaceuticals dispensed to the patients	4735 €	4735 €

The new system could bring an increase in the pharmaceuticals revenue of 2.453,31€ (4.592,95€ - 2.139,64€) over a period of 10 days. Assuming that these 10 days are representative of the ER activity, we can extrapolate the results over one year, which could procure an increase of 89.545,81€.

The management of the hospital provided us with an estimation of the implementation cost of this new system. The estimated price of the cabinet is 75.000,00€ (one central unit, 3 cabinets and one fridge) and 25.000,00€ for the setup.

The initial investment for that project is thus 100.000,00€. By taking into account only the financial gains from the billing, the Table 27 provides, for different life length of the investment, the internal rate of return of the project (IRR). As we can see it, the project is profitable if the cabinet is used at least 2 years.

Table 27. IRR for different life length of the project

	TIME					*IRR*
Option	0	1	2	3	4	
4	-100000	89.545,81	89.545,81	89.545,81	89.545,81	81%
3	-100000	89.545,81	89.545,81	89.545,81		72%
2	-100000	89.545,81	89.545,81			49%
1	-100000	89.545,81				-10%

1.4 Mathematic model

The implementation of the automated dispensing cabinet has shown to lead to potential improvements on the financial and quality indicators. This new system is part of an inventory management system that has to be managed with an appropriate policy. The current policy leads to shortage of some products while there are too many of others.

We thus take the opportunity to review the current system and to propose a new inventory management policy. We apply a mathematical model to determine both tactical and operational decisions. From the tactical point of view, we determine how much inventory we need and where to locate it, i.e. in the central pharmacy or in the emergency room. From an operational point of view, we determine how much and which items to order to run the system on a day-to-day basis. As we showed it in the literature review about inventory management, numerous models have been developed so far, taken into account different factors and constraints of the problem.

The demand in the ER is said to be random because the number of patients and their pathologies are not known in advance. We also take into account the most possible characteristics of the problem. To construct a model, we have then the following characteristics to consider:

- Stochastic and non stationary demand: patients' arrival at the ER is completely random; the patients' demand for pharmaceuticals is therefore also random.
- Capacity-constraint: the number of medicines stored is limited.
- Multi-product: the ER is concerned about the availability of all pharmaceuticals at the same time.
- Multi-echelon: the holding costs at the central pharmacy are lower than those at the ER; once an item is brought to the ER, there is no carry over with the other care units

and there could be some repacking between the units delivered to the central pharmacy and the units delivery delivered to the ER.

The model should be in addition computationally efficient to test different scenarios and to readapt the parameters to take into account changes in the demand patterns and in the prices of pharmaceuticals. Based on the characteristics of our problem, we choose to adapt a mathematical model that has been developed by (Muckstadt et al. 2001) and that is computationally efficient. The authors suggest a mathematical model to determine the PAR levels. By comparison with the current quantities kept in storage, we will be able to determine the savings that could be realized due to the inventories in excess. We then can determine the inventory turnover, the service provided and the operating costs. This inventory management policy is based on the newsboy model. Before going further, we recall the basis principle of this stock model.

1.4.1 The newsboy model

The model (Hadley et al. 1963) received its name from the particular situation it describes: each day, the owner of a newsstand has to decide the number of copies of a particular paper to stock to face the demand of the day. If he doesn't supply enough papers, he will lose sales and if he buys too many quantities, he will have unsold copies. The demand for the newspaper is stochastic over a single period and only one procurement is made. There is an underage cost, c_u , associated with each demand that cannot be met, and there is an overage cost, c_o , associated with each copy that is not sold.

a. Optimal quantity determination

The objective of the newsstand owner is to determine the number of copies that will balance his underage and overage cost, and so minimize his total cost. The simplest derivation is a marginal analysis. We consider the Q^{th} unit purchased. It will be sold if, and only if, the demand x equals or exceeds Q; otherwise, an overage cost will be incurred for this Q^{th} unit. However, if the demand equals or exceeds Q, he has avoided an underage cost by having the Q^{th} unit available. If the expected overage cost associated with acquiring it exceeded the expected saving in underage costs, he would not want to acquire that unit. The Table 28 summarizes this reasoning.

Table 28. Marginal analysis of the newsboy model

Specific cost element	*Probability that the specific cost element is incurred or avoided by the acquisition of the Q^{th} unit*	*Expected value of the specific cost element associated with the Q^{th} unit*
Overage cost	$Prob(x \leq Q)$	$c_o * Prob(x \leq Q)$
Underage cost	$Prob(x > Q) = 1 - Prob(x \leq Q)$	$c_u * [1 - Prob(x \leq Q)]$

The last unit he wants to acquire (Q^*) is one where the expected overage cost incurred exactly equals the expected underage cost saved; that is, Q^* must satisfy:

$$c_o * Prob(x \leq Q^*) = c_u * [1 - Prob(x \leq Q^*)] \quad (eq. 1.1)$$

Or

$$\mathrm{Prob}(\mathrm{x} \le \mathrm{Q}^*) = \frac{\mathrm{c_u}}{\mathrm{c_u} + \mathrm{c_o}} \quad (eq. 1.2)$$

The probability that the demand is equal or lower than Q^* determines the service level he wants to achieve to the client.

b. The cost function

The expected cost of the owner of the newsstand if he procures Q papers, is

$$E[C(Q)] = c_o E[Q - x]^+ + c_u E[x - Q]^+ \; (eq. 1.3)$$

Since he will face an overage cost for the units in excess if $Q > x$ and an underage cost for the units in shortage if $Q < x$.

The shape of the cost function will depend upon the statistical law followed by the demand. We refer to (Silver et al. 1998) for a detailed explanation of the newsboy function. If the demand is considered as normally distributed with a mean μ and a standard deviation σ_x and k defined as $k = \frac{Q-\mu}{\sigma_x}$, the expected cost is :

$$E[C(Q)] = c_o k \sigma_x + (c_o + c_u)\sigma_x L(k) \quad (eq. 1.4)$$

Where $L(k)$ is called the loss function and is defined as:

$$L(k) = \frac{1}{\sqrt{2\pi}} e^{-\frac{k^2}{2}} - k(1 - Prob(x \le k) \; (eq. 1.5)$$

The loss function determines the expected shortage per replenishment cycle which means the number of units expected to be in shortage in each replenishment cycle.

The expected shortage per replenishment cycle, ESPRC, in the case of a normal distribution of mean μ_x and standard deviation σ_x is:

$$ESPRC = \sigma_x * L(k) \; (eq. 1.6)$$

The newsboy model can be generalized to multiple products, periods and echelons and take into account additional constraints as the limited capacity. However, the more complete the model is the more computational time is needed to solve it. Muckstadt (Muckstadt et al. 2001) proposes a computationally efficient approach to solve the capacited multi-item, multi-echelon system with stochastic demand and cyclic demand, which corresponds to the characteristics of our problem. We will now explain the approach proposed by Muckstadt after having described our problem.

1.4.2 Problem statement

The system we consider was described through the knowledge building in chapter 4. We shortly recall some of the key characteristics we need for the inventory management model.

The emergency rooms are resupplied 2 times a week from the central pharmacy, with a lead time of one period. The pharmaceuticals ordered are available at the beginning of the next period. This is a two-echelon system. We consider that the central pharmacy has a limited capacity because the reception platform can handle only a limited number of packs every day due to personnel and infrastructure reasons. The stocks in the emergency rooms are managed according to a PAR level policy and are filled in every period. These levels are verified one time a month. The demand faced at the emergency rooms for pharmaceuticals is completely random and independent between the periods. This assumption seems reasonable since the length of stay of the patients in the ER is smaller than the considered period. The Figure 37 describes the system under consideration. It corresponds to the pharmaceuticals ordering process we identify in the Figure 23 to resupply the inventory located in the medico-technical unit.

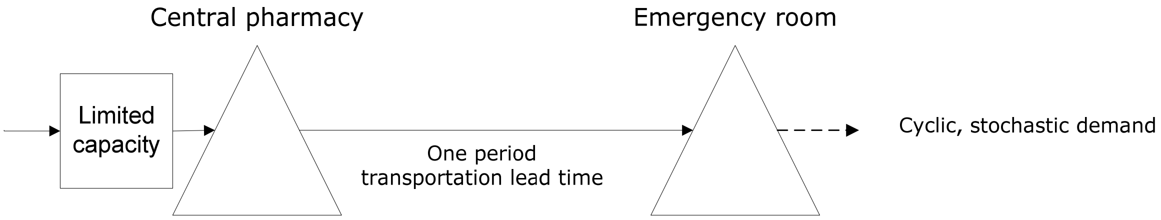

Figure 37. Two-echelon inventory system

The ER is concerned with the availability of all pharmaceuticals at the same time. The service level should be as high as possible. The demand at the emergency room is not backordered. In fact, if a pharmaceutical is not available, a nurse goes to the central pharmacy and picks up the product in shortage. During that time, the nurse is not available for care activities. To reflect that inconvenience, we keep a backorder cost that we set to a high value.

We apply the model of Muckstadt (Muckstadt et al. 2001). This model doesn't take into account explicitly the notion of service level. In fact, the introduction of a service level aspect in the problem will make the problem difficult to solve since it will lead to a non convex set of constraints (Nicholson et al. 2004). On the contrary, the model assumes that all demands are backordered. The backorder cost reflects the fact that a nurse should go in emergency to the ER to pick up the medicine. We therefore decide to put high backorder costs in order to force the model to have high availability for the products. The model also considers multiple distribution centers at the second echelon. We consider only one location at the second echelon, the emergency room but it would allow further extensions to model other care units.

1.4.3 Sequence of events, assumptions and notations

The materials are moved from the central pharmacy to the emergency rooms. The Figure 38 represents the flow of materials over time. The periodic sequence of events is as follow:

- The inventory at the beginning of the period is the ending inventory of the prior period.
- Materials are received at the central pharmacy and at the ER.
- Demand is realized and materials are consumed at the ER.
- Inventory costs are assessed.
- A new inventory plan is computed.

- The next period's replenishment order is confirmed for delivery at the beginning of the next period.
- Replenishment orders are placed with external suppliers for delivery after some known and constant lead time.
- The inventory at the end of the period is carried forward.

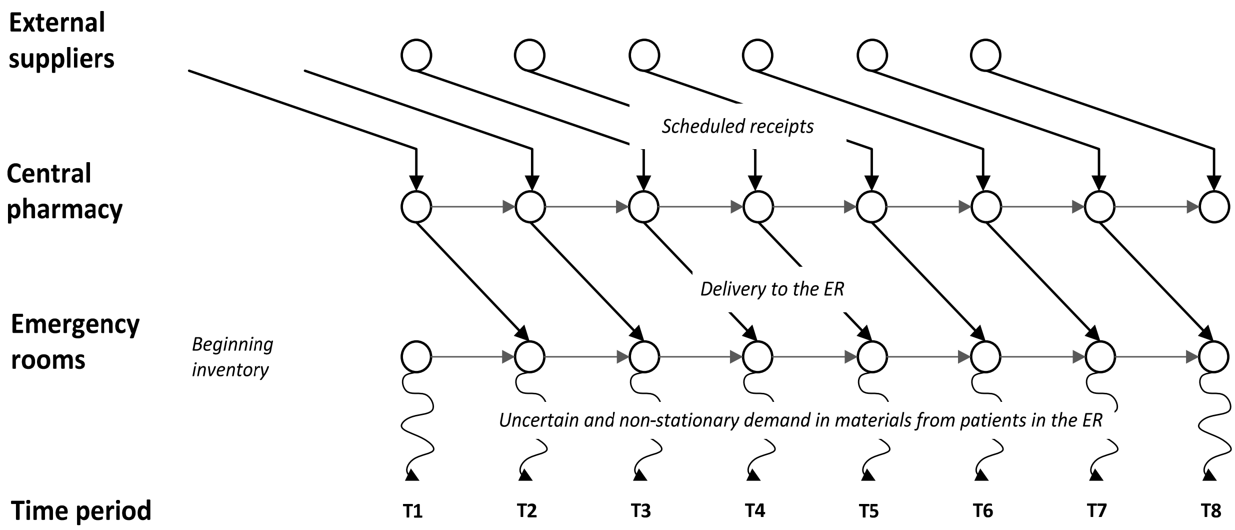

Figure 38. Material flow interdependency between the external suppliers, the central pharmacy and the emergency rooms

The model has the following characteristics:

- Indices
  - n: number of periods in a cycle; n=1,…., N;
  - i: number of pharmaceuticals stored in the cabinet; i=1, …, P.
- Parameters
  - h_{ij}: holding cost of medicine i per period, depending of the storage location j (j=0 if it is at the central pharmacy, j=1 if it is at the ER). The holding cost is higher at the ER, reflecting the lack of storing area at that place;
  - π_{ij}: backorder cost for the pharmaceutical i. We consider that there is no backorder cost at the central pharmacy;
  - D_{in}: random variable for the pharmaceutical demand of medicine i during the period n. We consider that these variables are normally distributed, considering the same assumption as (Dellaert et al. 1996);
  - μ_{in} =E(D_{in}); the average demand for medicine i during period n;

- σ_{in} : standard deviation demand for medicine i during period n;
- $\overline{D}_{in} = \sum_{t=1}^{n} D_{it}$: the cumulative demand for medicine i through period 1,…, n;
- $\bar{\mu}_{in} = \mathrm{E}(\overline{D}_{in})$: the cumulative average demand for medicine i through period 1,…, n;
- $\bar{\sigma}_{in}$: cumulative standard deviation demand for medicine i through period 1,…, n;
- T: total stored quantities that are available in the system at the beginning;
- C_n : maximum capacity for the period n.

- Decisions variables
  - s_{in} : stock level for medicine i during period n;
  - $\bar{s}_{in}$: cumulative stock level for medicine i through period 1,…, n;
  - r_i : purchased quantities of medicine i over the cycle;
  - T_i: initial inventory of medicine i;
  - $\bar{y}_{in}$: cumulative purchased quantities of product i from period 1 to period n increased by the initial stock T_i ;
  - z_{ink} and w_{ik} are binary variables we use to solve the problem and to compute the stock level and the unit provided in the system.

1.4.4 The unconstrained model

Firstly, the unconstrained model over one single period is solved, considering P products. We consider that the inventory decisions about the N periods are independent. At the end of each period, the pharmaceuticals inventory left over is thus considered disposed. Because the model is unconstrained, we consider only the inventory management policy at the last echelon, in the emergency room. We thus take into account the holding costs and the backorder costs at this level. The objective is to determine the stock level s_{in} for item i at the emergency room in period n that minimize the current period cost's expected costs. We solve

$$\min_{s_{in}} \sum_{n=1}^{N} \sum_{i=1}^{P} G_{in}(s_{in}) \qquad (eq. 1.7)$$

Where, $G_{in}(s_{in})$ is the expected cost for the pharmaceutical i in period n. If we replace in the equation 1.4 from the newsboy model, we get:

$$G_{in}(s_{in}) = h_{ij}(s_{in} - \mu_{in}) + (h_{ij} + \pi_i)\sigma_{in} L\left(\frac{s_{in} - \mu_{in}}{\sigma_{in}}\right) \ (eq. 1.8)$$

For computational efficiency, we use a piecewise linear representation of the cost function based on the first forward difference of the cost, as suggested by Muckstadt (Muckstadt et al. 2001).

$$\min_{z_{ink}} \sum_{n=1}^{N} \sum_{i=1}^{P} \left(G_{in}(0) + \sum_{k=0}^{K} \Delta G_{in}(k) z_{ink} \right) \ (eq. 1.9)$$

where

$$\Delta G_{in}(s_{in}) = G_{in}(s_{in} + 1) - G_{in}(s_{in}) \ (eq. 1.10)$$

And $G_{in}(0) = \pi_i \mu_{ij}$; if there is no stock level, all the demand is backordered.

By considering the periods independent of each other, the interdependence decisions between periods is ignored. However, in the ER, because of the demand variability, it could be less expensive to left over some stock to face a surge in the demand the next period. To take into account the interdependency between the decisions, the cumulative demand of the pharmaceuticals is used. The cost function of the equation 1.8 is transformed as followed:

$$\bar{G}_{in}(\bar{s}_{in}) = h_{ij}(\bar{s}_{in} - \bar{\mu}_{in}) + (h_{ij} + \pi_i)\bar{\sigma}_{in} L\left(\frac{\bar{s}_{in} - \bar{\mu}_{in}}{\bar{\sigma}_{in}}\right) \ (eq. 1.11)$$

$$\Delta\bar{G}_{in}(\bar{s}_{in}) = \bar{G}_{in}(\bar{s}_{in} + 1) - \bar{G}_{in}(\bar{s}_{in}) \ (eq. 1.12)$$

The program to be solved is thus

$$\min_{\bar{z}_{ink}} \sum_{n=1}^{N} \sum_{i=1}^{P} \left(\bar{G}_{in}(0) + \sum_{k=0}^{K} \Delta \bar{G}_{in}(k) \bar{z}_{ink} \right) \ (eq. 1.13)$$

s.t.

$$0 \le \bar{z}_{ink} \le 1 \quad \forall i, n, k \quad (eq. 1.14)$$

The solution is given by:

$$\bar{z}_{ink} = \begin{cases} 1 \ if \ \Delta\bar{G}_{in}(k) < 0 \\ 0 \ otherwise \end{cases} \ (eq. 1.15)$$

And

$$\bar{s}_{in} = \sum_{k=0}^{K} \bar{z}_{ink} \ (\text{eq. } 1.16)$$

To find the stock level for each product, each period, we compute the first forward difference $s_{in} = \bar{s}_{i,n+1} - \bar{s}_{in}$ for n=1, 2, …, n and $\bar{s}_{i0} = 0$.

1.4.5 The capacited problem

As we mentioned it, the hospital has a limited capacity. It would be needed to supply more pharmaceuticals some periods to face surge in the demand the coming periods. We consider that the system starts with an initial inventory, T, which represents the total amount of inventory in the system. Each product has an initial inventory T_i so that $\sum_{i=1}^{P} T_i = T$. At the end of each cycle, the stock should return to that initial state. It reflects the fact that one time per month, the PAR levels are checked and readjusted if needed.

To reach that level at the beginning of each new cycle, excess demanded quantities may be purchased or excess stored quantities may be returned. $H_i(r)$ represents the expected excess demand quantities over the cycle and that will be ordered to the supplier at a cost a_{over} $(max_i\{\pi_i\})$. $H_i(r)$ is expressed by the equation 1.17.

$$H_i(r) = E[\bar{D}_{iN} - r]^+ \text{ (eq. 1.17)}$$

Equation 1.18 is the first forward difference of $H_i(r)$:

$$\Delta H_i(r) = H_i(r+1) - H_i(r) = Prob\{\bar{D}_{iN} \leq r\} - 1 \ (eq. 1.18)$$

To compute $H_i(r)$, the authors constructs a piecewise linear approximation, formulated in the equation 1.19

$$H_i(r) = H_i(0) + \sum_{k=0}^{r-1} \Delta H_i(k) = \bar{\mu}_{iN} + \sum_{k=0}^{r-1} \Delta H_i(k)\ , for\ r > 0 \quad (eq. 1.19)$$

Where $H_i(0) = \bar{\mu}_{iN}$ means that, if there is no supply over the cycle, all the demand will have to be ordered at higher cost.

In the same way, $J_i(r)$ represents the excess stored quantities compared to the initial stock. These quantities will be returned to the suppliers, a_{dispo} $(min_{i,j}\{h_{ij}\})$

$$J_i(r) = E[r - \bar{D}_{in}]^+ \quad (eq. 1.20)$$

$$\Delta J_i(r) = Prob\{\bar{D}_{in} \leq r\} = H_i(r) + 1 \quad (eq. 1.21)$$

$$J_i(r) = \sum_{k=1}^{r-1} \Delta J_i(k) \qquad (eq. 1.22)$$

If any quantity is supplied, $J_i(0) = 0$

If we integrate all this information into the cost function, we obtain:

$$\varphi(T) = \min_{\bar{z}_{ink}, w_{ik}, \bar{z}_{ink}} \sum_{n=1}^{N}\sum_{i=1}^{P} h_{i0}(\bar{y}_{in} - \bar{s}_{in}) + \sum_{n=1}^{N}\sum_{i=1}^{P}\left(\bar{G}_{in}(0) + \sum_{k=0}^{K} \Delta\bar{G}_{in}(k)\bar{z}_{ink}\right) + a_{over}\sum_{i=1}^{P}\left(H_i(0) + \sum_{k=0}^{K}\Delta H_i(k)w_{ik}\right) + a_{disposal}\sum_{i=1}^{K}(\Delta J_i(k)w_{ik}) \quad (eq.1.23)$$

s.t.

$$\sum_{i=1}^{P}\left(\bar{y}_{in} - \bar{y}_{i,n-1}\right) \leq C_n \qquad \forall n \quad (eq.1.24)$$

$$\bar{y}_{i0} = T_i \quad \forall i \qquad (eq.1.25)$$

$$\sum_{i=1}^{P} T_i = T \quad \forall i \ (eq.1.26)$$

$$\bar{y}_{\mathrm{iN}} = \mathrm{T_i} + \sum_{\mathrm{k=0}}^{\mathrm{K}} \mathrm{w_{ik}} \qquad \forall i \ (eq.1.27)$$

$$\bar{s}_{in} = \sum_{k=0}^{K} \bar{z}_{ink} \qquad \forall i, n \ (eq.1.28)$$

$$\bar{s}_{in} \leq \bar{y}_{in} \qquad \forall i, n \quad (eq.1.29)$$

$$\mathbf{0} \leq \bar{z}_{ink} \leq \mathbf{1}, \qquad \forall i, n, \mathrm{k} \quad (eq.1.30)$$

$$\mathbf{0} \leq w_{ik} \leq \mathbf{1} \qquad \forall i, n, \mathrm{k} \quad (eq.1.31)$$

$$\bar{y}_{in} \geq \bar{y}_{i,n-1} \qquad \forall i, n \quad (eq.1.32)$$

The cost function 1.23 has 4 terms: the first one computes the holding costs of the pharmaceuticals at the central pharmacy; the second one determines the backorder and holding costs of the products in the ER; the third one is the end-of-cycle cost incurred if the demand for pharmaceuticals is higher than forecasted; the fourth one is the end-of-cycle cost incurred if the demand for pharmaceuticals is lower than forecasted.

Constraints 1.24 are capacity constraints, limiting the quantities supplied to the maximum capacity. Constraints 1.25 specify that the initial stock of each product is the initial supply. Constraints 1.26 ensure that the sum of initial stocks of all products equal the initial total quantities in the system. Constraints 1.27 define the cumulative storage over the cycle. Constraints 1.28 are about the cumulative stock level for medicine i during the period n. Constraints 1.29 put a limit on the cumulative inventory. Constraints 1.30 and 1.31 are binary variables; constraints 1.32 ensure that the decisions relative to the cumulative storage are at least equal to the former period.

The cost function that we minimize (1.23) assumes however that an initial inventory is fixed. To determine this value, we use the unconstraint model (1.13) and (1.14) and we fix an initial maximum stock at $\sum_{i=1}^{P}\sum_{n=1}^{N} s_{in}$. We explore then from that upper bound the cost function looking for the T value that minimizes $\varphi(T)$ (1.23). This value is the total initial stock in the system.

In the case of the capacity constrained problem, the model is used to determine the initial quantity of each individual item, T_i, the product quantities to buy each period and the product quantities to supply to the emergency rooms. The total initial inventory T is given.

To solve the problem, we thus first resolve the uncapacited problem (1.13) and (1.14). It provides us the maximum initial inventory in the system. We then solve the capacited problem (1.23) using as total initial stock in the system this maximum value. We solve it several times, decreasing each time the initial stock of a certain quantity. We thus get an estimation of the inventory policy cost for different initial inventories. We choose the initial inventory that minimizes the cost. The algorithm of resolution is given in the Figure 39.

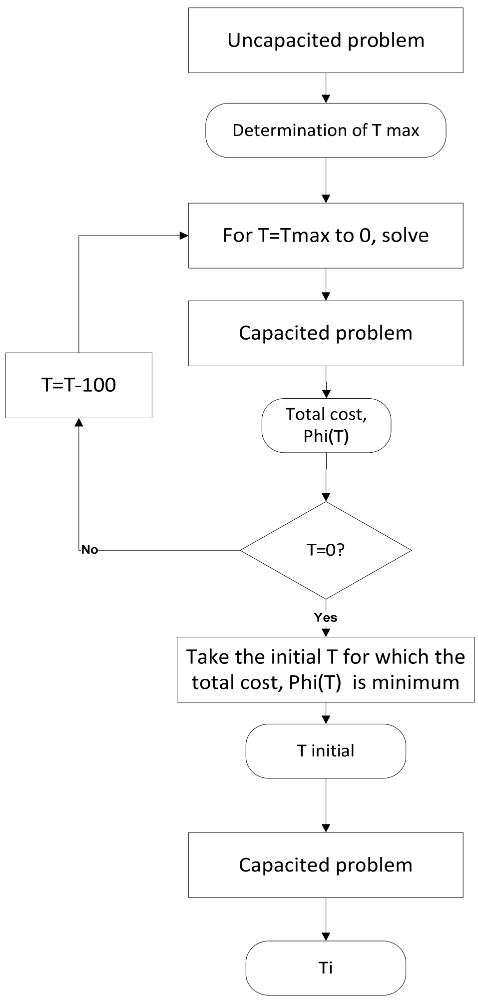

Figure 39.Algorithm of resolution

1.5 Application to the Belgian hospital of our concern

The mathematical model is tested on real data from the hospital with which we are collaborating. The programs were run under Windows 2000 with a Pentium IV processor and 1 Gb RAM. The program has been coded and run with Xpress Mosel as solver.

The considered parameters are:

- Based on the stocktaking units we made, we counted 61 products stored in the ER (medicines). We don't take into account the sterile material.
- The ER inventory is replenished two times a week and one per month the PAR level are reviewed. We consider each period of 3 days and 10 periods in a cycle, which corresponds to a month.
- The capacity constraint is fixed at 600 items and is constant over the periods.

The holding cost is higher at the ER, reflecting the lack of storing area at that place. After talking to the pharmacists and based on experience we consider a fraction of the pharmaceuticals price; 10% for the central pharmacy and 50% for the ER; the backorder costs are very difficult to estimate. In addition, the nurses are more concerned by the service level they provide the patients. We thus determine the backorder costs based on the holding costs and the service level they want to achieve. We put the service level at 99,99%. To reach this level, we need to set up the backorder costs at 5000% to ensure that there will be as few backorders as possible. This equation is based on the equation 1.2.

$$\frac{price * 5000\%}{(price * 5000\% + price * 50\%)} \cong 99{,}99\%$$

This model ensures a service level of 99%. For instance, for the first product, we have

$$s = \frac{\pi}{\pi + h} = \frac{21{,}6}{21{,}6 + 0{,}0216} \cong 99{,}9\%$$

The running of the uncapacited model gives us the quantity of each item to supply each period in order to minimize the cost. Through the 10 periods, a total of 4223 items were supplied in the system. The Figure 40 represents the comparison between the current stock levels of each item and the average stock levels for each period proposed by the inventory model. The Figure 41 provides the same results but only presents the most consumed items.

We can see that the model suggests significant cuts in the amount of inventories kept in the ER.

The model suggests the PAR levels for each period; the Figure 42 shows these variations that can be explained by the variation in the demand. The Figure 43 provides the same analysis focusing on the most consumed items.

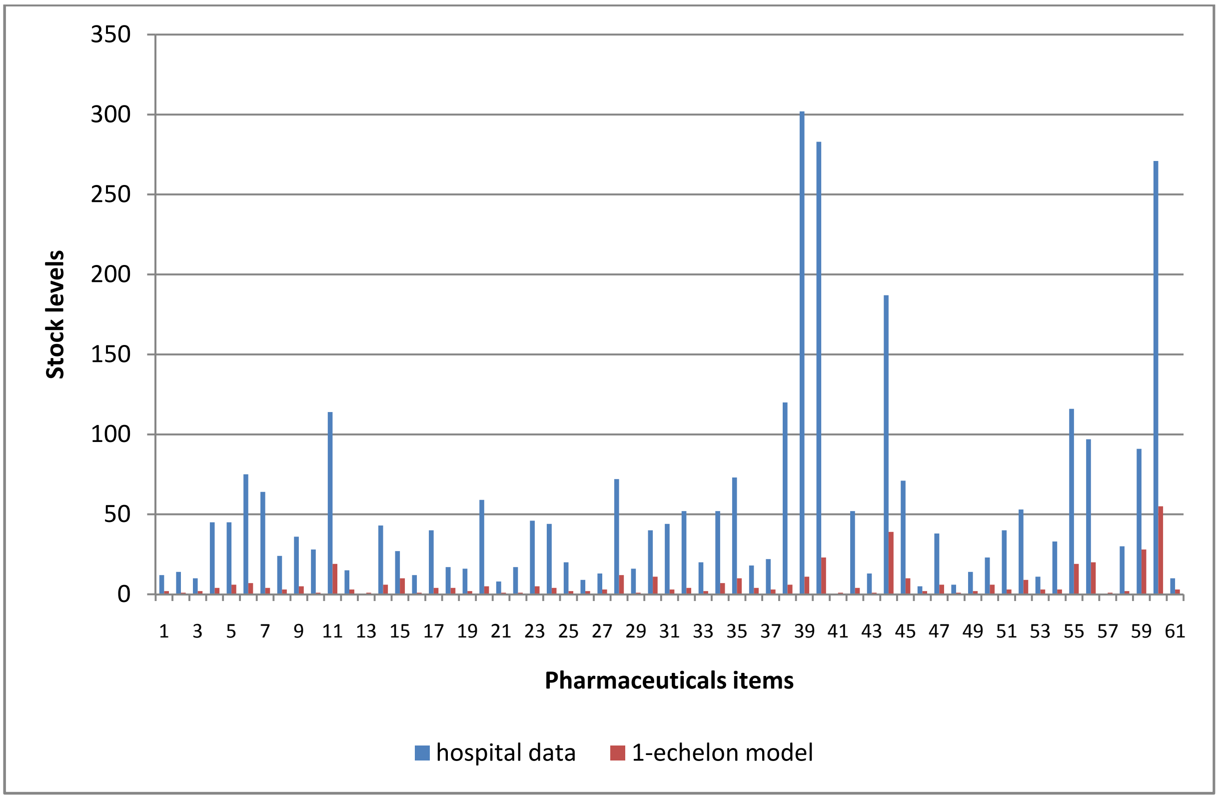

Figure 40. Comparison between the current stock and the average stock proposed by the model

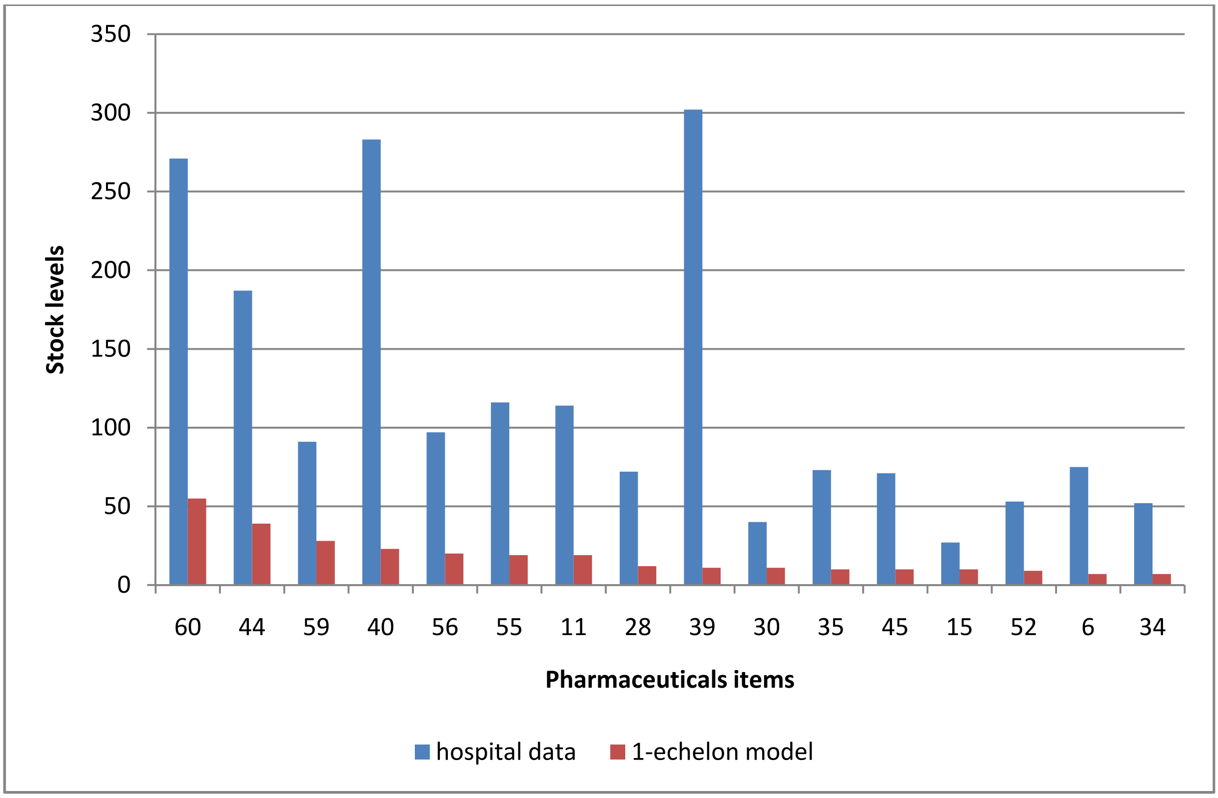

Figure 41. Comparison between the current stock and the average stock proposed by the model for the most consumed items

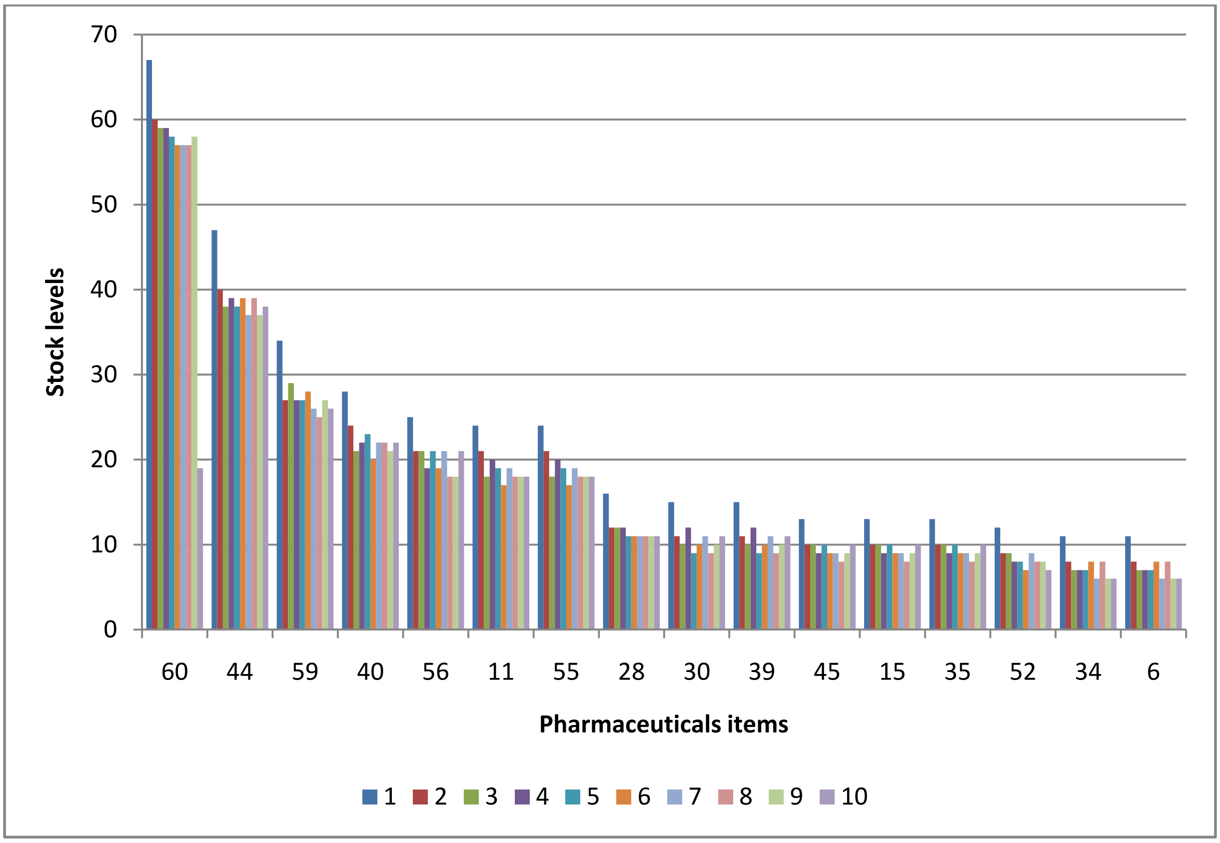

Figure 42. Par levels suggested by the model for each item each period

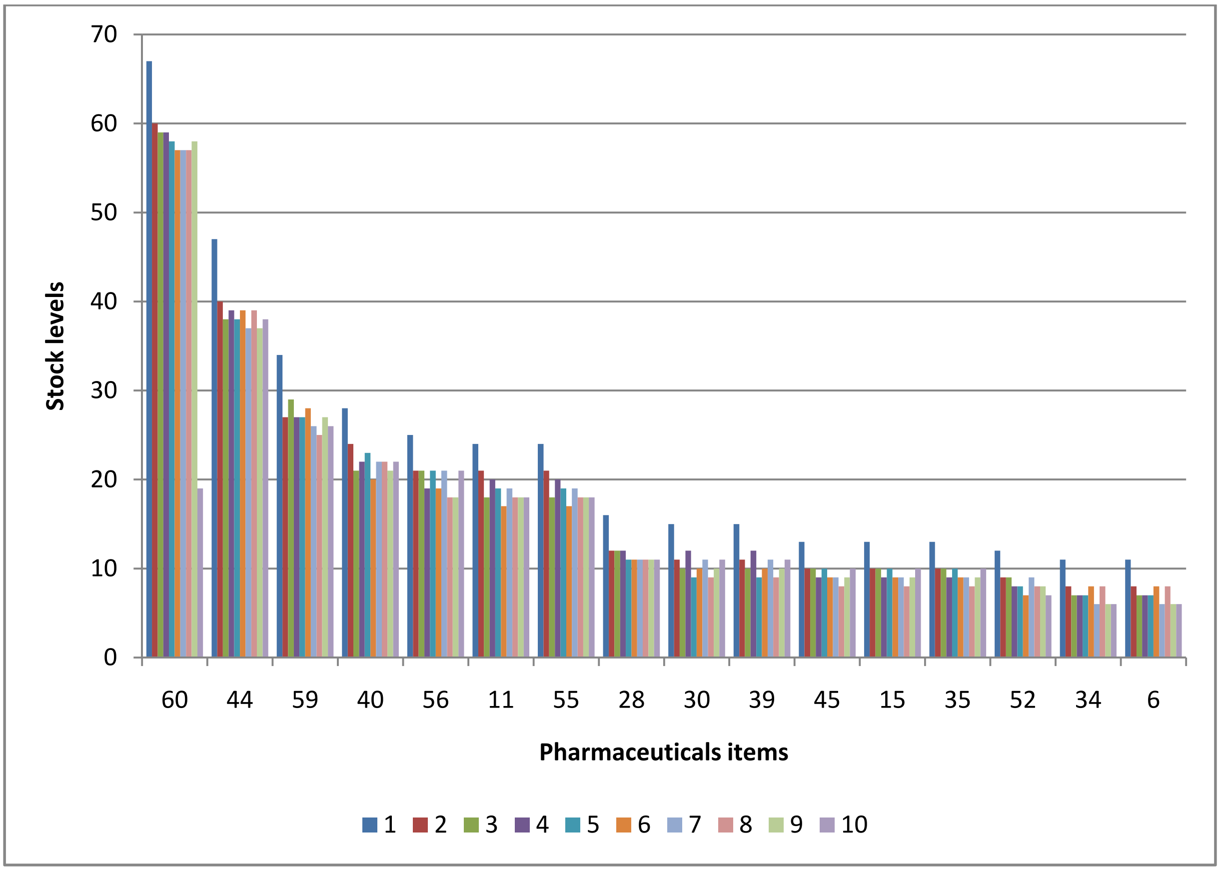

Figure 43. Par levels suggested by the model for the most consumed items

We use the total amount of products supply in the system as the first value of the total initial stock for the capacited model. We then run it with different values of the initial stock, starting from 4300 and decreasing by 100 until 0. The Figure 44 illustrates the evolution of the total cost.

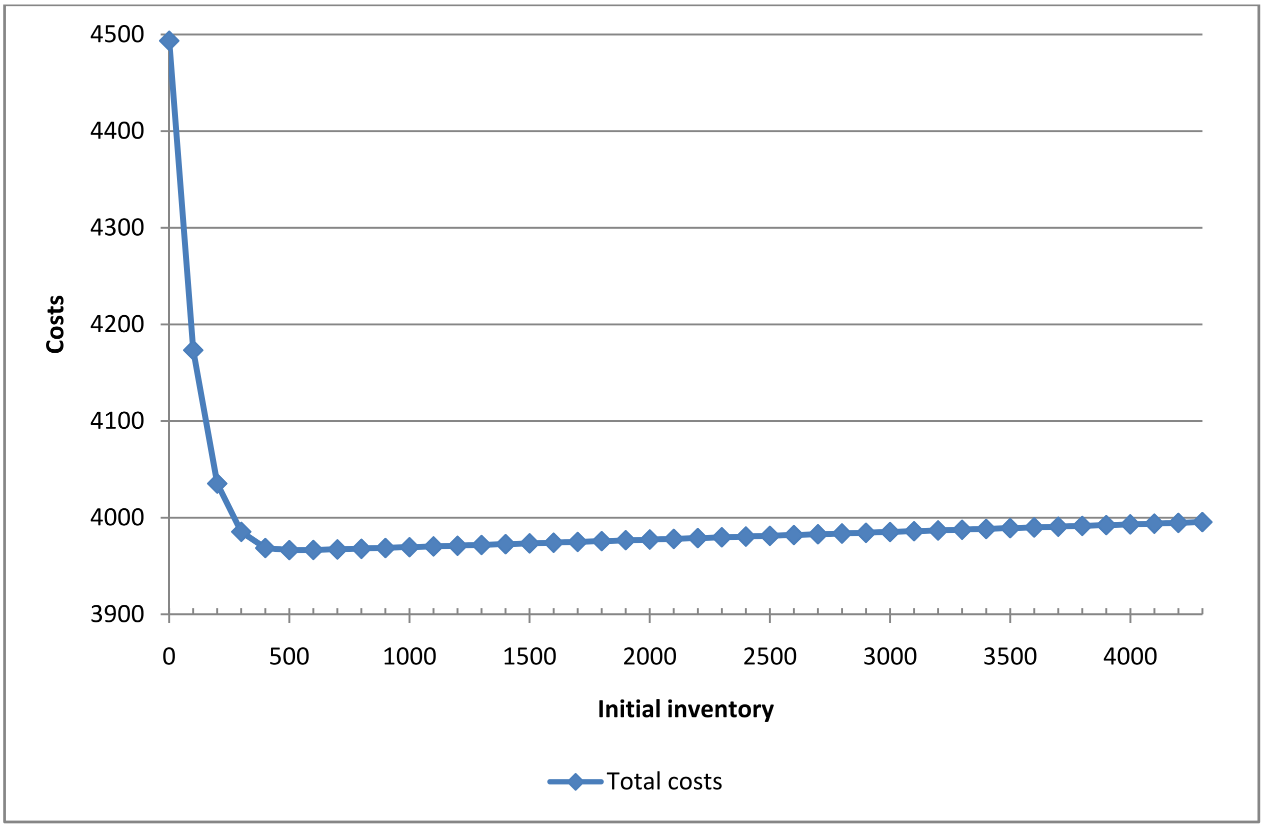

Figure 44. Evolution of the total costs of inventory depending on the total initial inventory level

The initial inventory which provides the lower total cost is 500 items. We then run this procedure again with an initial inventory varying between 400 and 600 items by 1 unit. The initial inventory leading to the minimum cost is 422 items with a cost of 2.462,22€.

The Figure 45 provides a comparison between the three inventory management policies: the current situation, the level of inventory suggested by the 1-echelon model and the level of inventory suggested by the two-echelon model. Both quantities suggested by the 1-echelon and 2-echelon models are identical for the quantities delivered to the ER. Indeed the quantities supplied at the ER are determined based on the demand, the holding costs and backorder costs at the ER. Since the holding costs at the ER are higher than the one at the central pharmacy (CP), this latest plays the role of a stock keeper: due to the capacity constraint, the units will be stored at the CP before being send at the ER.

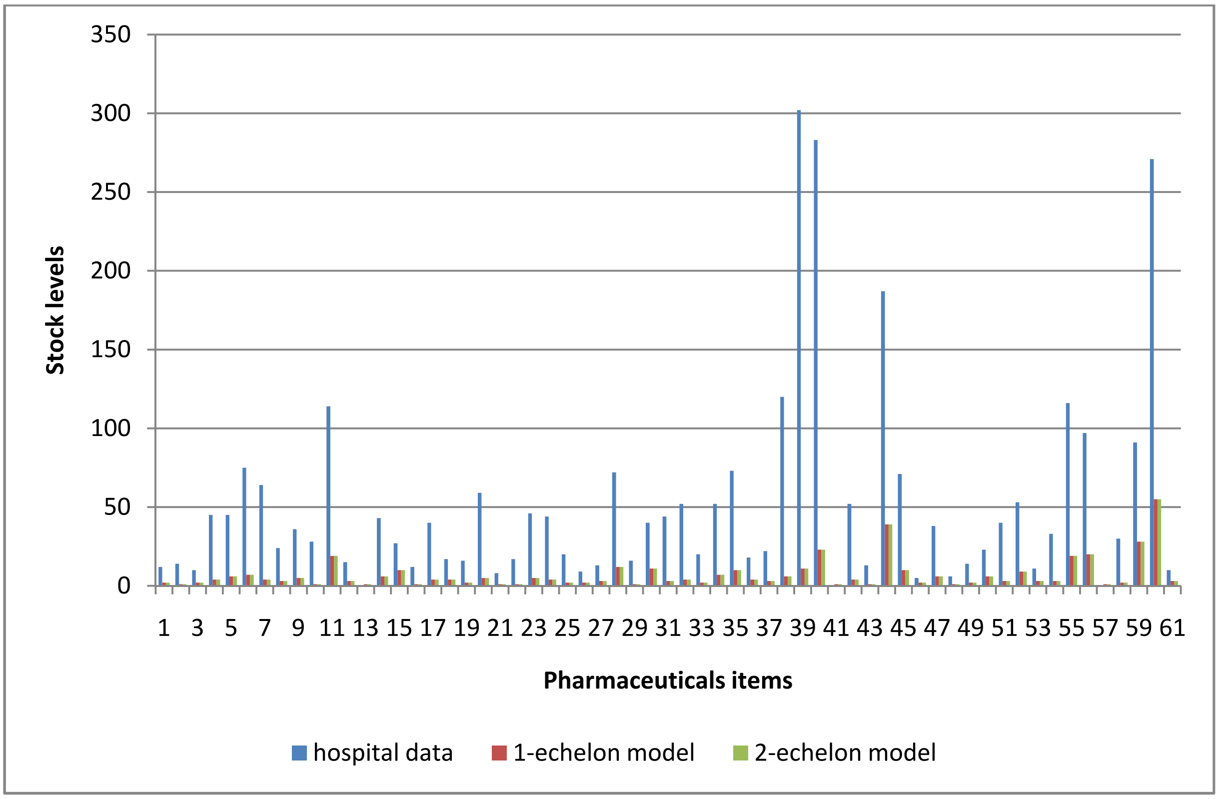

Figure 45. Comparisons between the current stock levels and the average stock levels proposed by the uncapacited and the capacited model

We have no data about the number of emergency orderings done by the nurses to the clinic pharmacy. Through the interviews we led, we learned that this happens at least one time every week, which leads to a service level of 50%. The parameter we used for this optimization should provide a service level of 99% which is a big improvement compared to the previous situation. The Table 29 shows the costs of the optimization models. The inventory units at the ER are valued at their purchasing price. The cost of the inventory policy is also provided. The difference between the 1-echelon and 2-echelon policies is the amount of stock kept at the central pharmacy to face a surge in the demand and to palliate the limited reception capacity.

Table 29. Estimated inventory reduction through the application of the optimization model (estimated in €)

	cost
Value of the current system inventory	6.987,27 €
Values of the 1- and 2-echelon inventory	1.177,10 €
Cost of the 1-echelon inventory policy	2.461,89€
Cost of the 2-echelon inventory policy	2.462,22€

1.6 Conclusion

Through the knowledge building we did in the chapter 4, we identified a number of problems linked to the pharmaceuticals dispensing as the redundancy of activities, the lack of information system, an inadequate inventory management policy and problems in the distribution. We also build a scorecard to assess the situation while taking into account the different stakeholders perspectives. The corrective actions were identified. For the dispensing system, these corrective actions are more control of the processes and their simplification, the automation, the setup of an information system and an adequate inventory management policy.

In the context of the reorganization of the logistical activities, the hospital management wants to set up an automated dispensing cabinet. The test department would be the ER. This new system could solve most of the problems and corresponds to all corrective actions but it is needed to assess it. This project is still undergoing and we thus had to base ourselves on studies led in other hospitals to estimate some indicators. The tables on pages 110 and 111 present the performance measures according to the 4 perspectives of the balanced scorecard. The results coming from other studies are indicated in italic and underlined.

The automated dispensing cabinet will bring an automation of the medicines dispensing process and will lead to a simplification of the practices since a number of operations currently done manually will be automated. This cabinet is also linked to an information system. The traceability of the pharmaceuticals will therefore be increased, resulting in both a better quality service to the patient and a higher billing rate of pharmaceuticals. The workload of the nurses for administrative tasks linked to the medicines will also be lightened, which will allow them to have more time to dedicate to care activities. The new equipment has also to be piloted with an appropriate inventory policy to have the right amount of medicines available. We apply a multi-item multi-level base stock inventory policy with a capacity constraint. This policy suggests significant cuts in the amount of stock kept on the shelves while improving the service level.

The setup of such equipment seems valuable for the hospital. However, as in any project implying processes reorganization, it will be needed to provide the nurses and the personnel with the adequate training and change management to have the full benefice of the new system.

♦ ***Patient's perspective***

Objectives	*Indicators*	*Definitions*	*AS-IS*	*TO-BE*
Ensuring the patient's satisfaction	Number of unsatisfied patients	Number of patients who complaint	NA	NA
Reduction of the dispensing errors	Number of dispensing errors	Number of products that were inappropriately dispensed	*3%*	*0,4%*
Traceability improvement	% of non recorded pharmaceuticals	nb of dispensed pharma not recorded in the patient's file/nb of consumed pharma	39,41%	*2%*
Traceability improvement	% of misrecorded pharmaceuticals	nb of pharma recorded in the patient's file but not on the pharma list/nb of consumed pharma	15,40%	*1%*

♦ ***Finance perspective***

Objectives	*Indicators*	*Definition*	*AS-IS*	*TO-BE*
Costs reduction and income increase of the care unit	Total operating costs	Operating costs of the pharmacy (products)	6.987,27€	1.177,10 €
Reduction of inventory costs	Total holding costs	Cost of holding the pharmaceuticals in the ER		One month : 2462,00 €
Reduction of inventory costs	Total backorder costs	Cost of ordering the pharmaceuticals in emergency		
Increase of the number of billed medicines	Income	Income generated by the billed pharmaceuticals	78.096,86€	167.642,68€
Increase of the number of billed medicines	pharmaceuticals billing rate	1-(% non recorded pharma + % misrecorded pharma)	45,19%	*97%*

♦ ***Internal processes perspective***

Objectives	*Indicators*	*Definition*	*AS-IS*	*TO-BE*
Reduction of the time spent by nurses to manage the pharmaceuticals	% time spent by nurses to fill in the patient's file	Time spend to fill in the file/total working time	*28%*	*16,90%*
Red of the time spent by nurses to manage the pharmaceuticals	% time spent by nurses to order the pharmaceuticals	Time spend to order the pharmaceuticals /total working time	*10,20%*	*9,60%*
Traceability improvement	% of non recorded pharmaceuticals	nb of dispensed pharma not recorded in the patient's file/nb of consumed pharma	39,41%	*2%*
Traceability improvement	% of misrecorded pharmaceuticals	nb of pharma recorded in the patient's file but not on the pharma list/nb of consumed pharma	15,40%	*1%*
Reduction of the number of out-of-stock products	number of out-of-stock products	nb of out of stock products during a cycle (30 days)	5	<1
Reduction of the dispensing errors	% of errors due to the wrong amount of medicine dispensed	nb of pharma dispensed in the inappropriate qty/ total nb of pharma dispensed	3,50%	*0,20%*
Reduction of the dispensing errors	% of errors due to the wrong product dispensing	nb of pharma dispensed inappropriately/total nb of pharma dispensed	2,50%	*0,20%*
Reduction of the dispensing errors	% of errors due to the non dispensing of the prescribed drug	nb of non dispensed pharma/ total nb of pharma	0,50%	*0,10%*
Increase of the number of billed medicines	% of misrecorded pharmaceuticals	nb of pharma recorded in the patient file but not on the pharma list/nb of consumed pharma	15,40%	*1%*

- ***Learning and growth perspective***

Objectives	*Definition*	*AS-IS*	*TO-BE*
Implementation an inventory management system	Yes or No		YES
Implementation an information system	Yes or No		YES
Training of nurses	Yes or No		To do

2 *The operating rooms*

The modeling of the hospital activities gives us more insight into the OT working and the coordination of the different resources needed, as the personnel, the pharmaceuticals, the infrastructure and the surgeons. It also points some problems up.

The inventory management policy currently applied to the OT, based on PAR levels, leads to overstocking of some items while others are in short supply, causing additional costs. The inventory management model we proposed for the ER is however not suited for the OT because the demand is not random. The OT demand for pharmaceuticals follows some deterministic patterns generated by the block scheduling policy (Beliën et al. 2006). We also view that the way the OT time is currently managed is not optimal and lead to some difficulties as delays in planning because of the lack of nurses for instance. We thus propose a mathematical model to plan the surgical procedures by considering together the planning and the scheduling phase. This model may take into account renewable (surgeons, anesthesiologists, nurses) and nonrenewable (pharmaceuticals and sterile materials) resources. The objective is to minimize the opening costs of operating rooms and overtime expenses. This planning and scheduling could serve as an input for a MRP system to determine the pharmaceuticals quantities needed.

2.1 Problem statement

The traditional way to build the surgical activity time table is based on an approach in two steps as shown in the literature review, chapter 2: the planning assigns an operating day and a room and the scheduling determines the starting hours of the surgeries. This operating mode doesn't take into account the interactions between the planning and the scheduling phases. Indeed the resources are allotted during the first phase. Even if there are enough resources to meet globally the demand, it may lead to an infeasible schedule (Beliën et al. 2006). In fact, in that type of approaches, the resources (nurses, anesthesiologists) are linked to the operating rooms. While it is correct to consider that a certain number of nurses have to be allocated to an OR (surgical team), all surgical interventions don't require the same number of personnel: more nurses and anesthesiologists are required for a valve replacement than for a classic appendectomy. There could be enough resources to lead over the day the surgeries but the scheduling obtained making it infeasible if all heavy surgeries start the surgical day.

The surgical activity time tabling is made more difficult by some precedence constraints between the surgeries. When the head of nurses plans the surgical interventions, she takes into account the nature of the surgery to put the "infected" patients and the "non clean" surgeries at the end of the day to not contaminate the OR and to not need more time to clean and disinfect it. Indeed, some patients have a contagious disease and the OR needs to be clean thoroughly after their surgical interventions. Some surgeries, as most intestine interventions, are considered as "non clean" and require also more thorough cleaning before the next operation. If these precedence constraints are taken into account, we can draw the analogy between our problem and the project scheduling, which can be to some extent considered as a mix of planning and scheduling (Wall 1996). We can model the surgical procedures planning as a Resource-Constrained Project Scheduling Problem (RCPSP) (Hartmann 2001). However, the model we will first explain has so far no precedence constraints between the surgical interventions since we have no data about why the surgeries were sequenced in that particular order, due to privacy restrictions. By modeling it so far as a RCPSP, we will be able to improve it easily when this information will be registered. In addition, that way to model is more flexible and some computational efficient approaches are currently developed to solve it. We first explain the concept and then apply it to the planning and scheduling of the OT activity.

2.1.1 The Resource-Constrained Project Scheduling Problem description

This problem considers a set of activities to be scheduled such that the duration of the project, the makespan, is minimized. Thereby, technological precedence constraints have to be observed as well as limitations on resources required to accomplish the activities. Once started, an activity cannot be interrupted.

A number of resources are required to achieve the project. Resources can be renewable or non-renewable. Renewable resources are available each period without being depleted. A good example of renewable resources is personnel and equipment. Non-renewable resources are depleted as they are used. Resources vary in capability, cost and other performance measures. The resource availability may vary over the project period. They can also have additional constraints as temporal restrictions that limit the periods of time when they can be used. It is typically the case for limitations on working hours.

The project is subject to constraints and has to meet objectives. Constraints define the feasibility of the schedule. Objectives define the optimality of a schedule. Whereas objectives should be optimized, constraints must be satisfied. A feasible schedule satisfies all the constraints. Objectives can be for instance the minimization of the project duration but, most real problems are subject to multiple, often conflicting objectives such as minimization of costs, maximization of the net present value of the project, resources utilization, resources efficiency, number of due dates that were met or not.

In general, most RCPSP problems are NP-hard, meaning that there are no known algorithms for finding optimal solutions in polynomial time. Algorithms exist for solving exactly some forms of the problems, but they typically take too long when the problem size grows or when additional constraints are added.

2.2 Mathematical problem

The problem we consider is the scheduling of surgical procedures over a short time period (typically one week). The project management goal is to define and schedule the different surgeries and to assign them the available resources (human or material) under costs and time constraints (Roland et al. 2007).

The project has a length of D opening days. We consider that there are T periods in each day (here quarters of an hour).

We consider J non preemptive activities, the elective surgeries. Each surgical intervention j has a deterministic processing time p_j. To be performed, the surgery requires a certain amount of renewable resources. The renewable resources we consider are the personnel as the anesthetists, the nurses and the scrub nurses. The availability of renewable resources is constant for each period over the day. The availability of the resource can though vary over the period to take into account the variation over the week (there are fewer nurses during the weekend). The availability of nonrenewable resources is defined for the whole day. Non renewable resources are for instance specific materials as prosthesis, or blood.

Each operation *j* has to be carried out between an earliest and a latest starting day, ES_j and LS_j respectively. An operation cannot start before the admission day of the patient and has to be carried out within an acceptable amount of time to maximize the patient's satisfaction (Chaabane et al. 2007).

Each surgical treatment is assigned to a particular surgeon, c, who has his personal availability a day. However, it could be possible to affect a surgery to several surgeons to model the fact that in some hospitals surgeries are led by a pool of surgeons.

Each activity can be performed in one of the *S* operating rooms. If the surgeries can be performed in any one of the ORs, we model an open scheduling management policy; if the interventions can only take place in some specific OR at some determined time, we model a block scheduling management policy. Each of these rooms has a regular availability for day *d*, representing the normal opening hours of the room defined by a number of periods. Since we allow an elective operation to occur after the normal working hours, in overtime, a room has also a maximal availability for day *d* which depicts the total amount of periods available this day for this room (opening hours and overtime).

Each time an operating room is opened the hospital spends C^{open} €, and pays a fixed amount for each time unit an OR is opened in overtime, C^{over} € per time unit. Hence the objective is to minimize the costs associated with room openings and with overtime pay.

2.2.1 Assumptions and notations

The model has the following characteristics:

- Indices
    - j: number of surgical interventions to schedule; j =1,...,J.
    - s: number of operating rooms ;s =1,...,S.
    - d: number of opening days; d=1,…,D.
    - t: number of periods in a day; t=1,…, T.
    - c: number of surgeons; c =1,...,C.
- Parameters
    - p_j: operating duration of surgical intervention *j*

- ES_j: earliest starting day for surgical intervention *j*
- LS_j: latest starting day for surgical intervention *j*
- r_{jk}^{ρ} : amount of renewable resource $k \in \mathrm{K}^{\rho}$ requires for intervention *j*
- R_{kd}^{ρ}: availability of renewable resource *k* for day d
- R_{js}: OR *s* where the surgical intervention *j* can take place
- R_{cd}^{C}: availability of the surgeon *c* for day *d*
- r_{jk}^{ν}: amount of non-renewable resource $k \in \mathrm{K}^{\upsilon}$ requires for intervention *j*.
- R_{kd}^{ν}: availability of non-renewable resource *k* for day d
- D_{sd}^{N} : availability of room *s* for day *d*
- D_{sd}^{M} : the total amount of periods available for room *s* the day *d* (normal and overtime hours)
- C^{open}: opening cost of a room
- C^{over}: cost of opening a room in overtime, per period

- Decisions variables
  - x_{jsdt} : binary variable ; take value 1 when the surgical operation *j* starts in room *s* during day *d* and at time period *t*
  - z_{sd}: binary variable; take value 1 when room *s* is opened in day *d*
  - l_{sd}: overtime work in room *s* for day *d*

2.2.2 Mathematical programming formulation

The model formulation for our problem takes the following expression:

$$\min_{\mathrm{x,z}} \sum_{s=1}^{S} \sum_{d=1}^{D} \left(C^{open} z_{sd} + C^{over} max(M_{sd} - D_{sd}^{N}, 0) \right) \quad (eq. 2.1)$$

where the closing hour of a room *s* in day *d* is given by:

$$M_{sd} = \max_{j,t} \{ (t + p_j) x_{jsdt} \} \quad (eq. 2.2)$$

subject to:

$$ES_j \leq \sum_{s} \sum_{d} \sum_{t} d \; x_{jsdt} \leq LS_j, \qquad \forall j \quad (eq. 2.3)$$

$$\sum_{s} \sum_{d} \sum_{t} x_{jsdt} = 1, \qquad \forall j \quad (eq. 2.4)$$

$$\sum_{j}\sum_{s} r_{jk}^{\rho} \sum_{r=t-p_j+1}^{t} x_{jsdr} \leq R_{kd}^{\rho}, \quad \forall d, \forall t, \forall k \quad (eq. 2.5)$$

$$\sum_{j}\sum_{s}\sum_{t} r_{jk}^{\nu}\, x_{jsdt} \leq R_{kd}^{\nu}, \qquad \forall d, \forall k \quad (eq. 2.6)$$

$$\sum_{s}\sum_{j\in O(c)}\sum_{r=t-p_j+1}^{t} x_{jsdr} \leq R_{cd}^{C}, \quad \forall d, \forall t, \forall c \quad (eq. 2.7)$$

$$\sum_{t} p_j * x_{jsdt} \leq D_{sd}^{M} z_{sd}, \qquad \forall s, \forall d, \forall t \quad (eq. 2.8)$$

$$\sum_{j}\sum_{r=t-p_j+1}^{t} x_{jsdr} \leq 1, \qquad \forall s, \forall d, \forall t \quad (eq. 2.9)$$

$$\sum_{d}\sum_{t} x_{jsdt} \leq R_{js}, \qquad \forall j, \forall s \quad (eq. 2.10)$$

$$x_{jsdt}, z_{sd} \in \{0,1\}, \qquad \forall j, \forall s, \forall d\ , \forall t \quad (eq. 2.11)$$

where the binary variables (2.11) x_{jsdt} take value 1 when the surgical operation *j* starts in room *s* during day *d* and at time period *t* while z_{sd} take value 1 when room *s* is opened in day *d*.

A number of constraints are defined to ensure the feasibility of the OT planning:

- A surgical intervention has to take place between an earliest and latest starting day (2.3).
- A patient undergoes the surgery only once (2.4).
- There are a limited number of renewable resources (nurses, anesthesiologists) available to operate (2.5); the amount of renewable resources consumed at one given time by all operations undergoing cannot exceed the amount of resources available.
- The OT can use a certain amount of non renewable resources (surgical materials, medicines, etc.) each day: the total consumption of all surgeries of a day cannot go beyond that amount (2.6). The OR are also renewable resources. Since OR are managed according a block scheduling policy, an operation can only take place in the OR dedicated to the appropriate surgical specialty that day.
- Each surgery is performed by a surgeon and has to take place when he is available (2.7). In these latter, we sum over the operations attributed to each surgeon c and defined by the set O(c).
- A surgical operation only occurs during the opening hours. An operation cannot finish after the closing hours (2.8).

- Surgical interventions cannot overlap in an OR (2.9).
- A surgical intervention can only take place in the operating room dedicated to the appropriate specialty (2.10)

Expressed like this, the programming is nonlinear since the objective function contains the nonlinear term $max(M_{sd} - D_{sd}^N, 0)$. This difficulty can be overcome by introducing a new variable $l_{sd} \geq 0$ and by adding two new constraints. The objective function (2.1) becomes:

$$\min_{\mathrm{z,l}} \sum_{s} \sum_{d} (C^{open} z_{sd} + C^{over} l_{sd}) \quad (eq. 2.12)$$

and the additional constraints are:

$$l_{sd} \geq (t + p_j) x_{jsdt} - D_{sd}^N, \qquad \forall j, \forall s, \forall d, \forall t \quad (eq. 2.13)$$

$$l_{sd} \geq 0, \qquad \forall s, \forall d \quad (eq. 2.14)$$

The variables l_{sd} represent the overtime work in room *s* for day *d*, if indeed there is overtime work, and are null otherwise. This new formulation makes the model a linear mixed-integer programming. The amount of overtime in each room is computed through the constraints (2.13); the overtimes are always positive numbers (2.14).

The MIP program is then solved with optimization software using a branch-and-bound algorithm. This way of resolution ensures to find the optimal planning, exploring all the possible solutions. However, while the number of resources and the number of surgical interventions are increasing, the number of feasible solutions explodes and it becomes hard to solve. Hence there exists no efficient method to solve it to optimality, only on small scale problems.

2.3 Application to the Belgian University hospital

The mathematical model is tested on real data from the hospital with which we are collaborating. The programs were run under Windows 2000 with a Pentium IV processor and 1 Gb RAM. The mixed-integer programming has been coded and run with Xpress Mosel as solver.

We received nameless data of surgical interventions over a two-month period (January and February 2006). To test our model, we take into account only the elective inpatient surgeries since the planning and scheduling of interventions are only done for these one.

Firstly, we had to clean the data. We consider the surgeries for which we had the number of resources consumed (surgeon, anesthesiologists, nurses), the starting time, the operating room and the length of the surgical procedure.

The hospital has 7 operating rooms dedicated to inpatients. Each room is devoted to a particular type of surgery or two. The rooms are managed in block scheduling. The allotment of the rooms to surgical specialties varies over the week. We base ourselves on the current allotment of the rooms to the surgeries represented in the Figure 46. A surgical intervention can take place only in the room dedicated to the appropriate specialty.

	OR1	OR2	OR3	OR4	OR5	OR6	OR7	
8h00 – 16h00	cardiology/ vascular surgery	plastic surgery	cardiology/ vascular surgery	orthopedy	urology	gynecology/ gastroenterology	gynecology/ gastroenterology	normal hours
17H00 – 20H00								overtime

Figure 46. Current allocation of the ORs to the different surgical specialties

An operating day is composed of 48 quarters of an hour (time periods) of which 12 are on overtime. A day starts at 8 AM and finish at 4 PM. Three hours of overtime are allowed. The planned surgeries may so take place until 7 PM. On basis of an estimation given by the OR manager, the room opening costs (personnel, cleaning, equipment) are evaluated at 2.040,00 € while overtime pay is estimated at 50,00 € per time period. For confidentiality reasons, these amounts were modified.

The surgical operation cannot take place before the admission of the patients and we consider that it has to occur within 3 days, during the week of his entrance in the hospital.

Solving a several days scheduling problem becomes extremely time-consuming when the problem size increases. We thus test our model on a 1 day and then on a 2 days scheduling.

2.3.1 One day

We first test our program to solve a one day scheduling. We choose therefore a Tuesday, which is more often the busiest day of the week in terms of number of interventions. Twelve surgeons are operating that specific day. Three renewable resources are considered, the anesthetists, the nurses and the scrub nurses. We have to schedule 19 surgical operations.

The actual timetabling, schematized on the Figure 47, uses the seven rooms and the cost reaches 15.580,00 €.

The scheduling we get in one hour computational time is presented in the Figure 48, and costs 14.480,00 €. The solution represents a cost decrease of 7,1% compared to the realized planning. One OR is also closed earlier.

The proposed planning doesn't take however into account the emergencies that are added during the day. We have therefore to evaluate how the proposed planning would be affected by the emergency surgeries. The day we consider, three emergencies were planned, one in the early morning and two in the late night as represented in red in the Figure 49. These additional operations won't affect the timetabling we proposed since they all occur during the normal closing hours of the OR (before 8AM or after 4PM).

Since we consider only a one day schedule, the number of possible planning is still limited but it is not of great help for the OR head nurse who has to plan the surgeries over the week. We thus test our model on a 2 days planning.

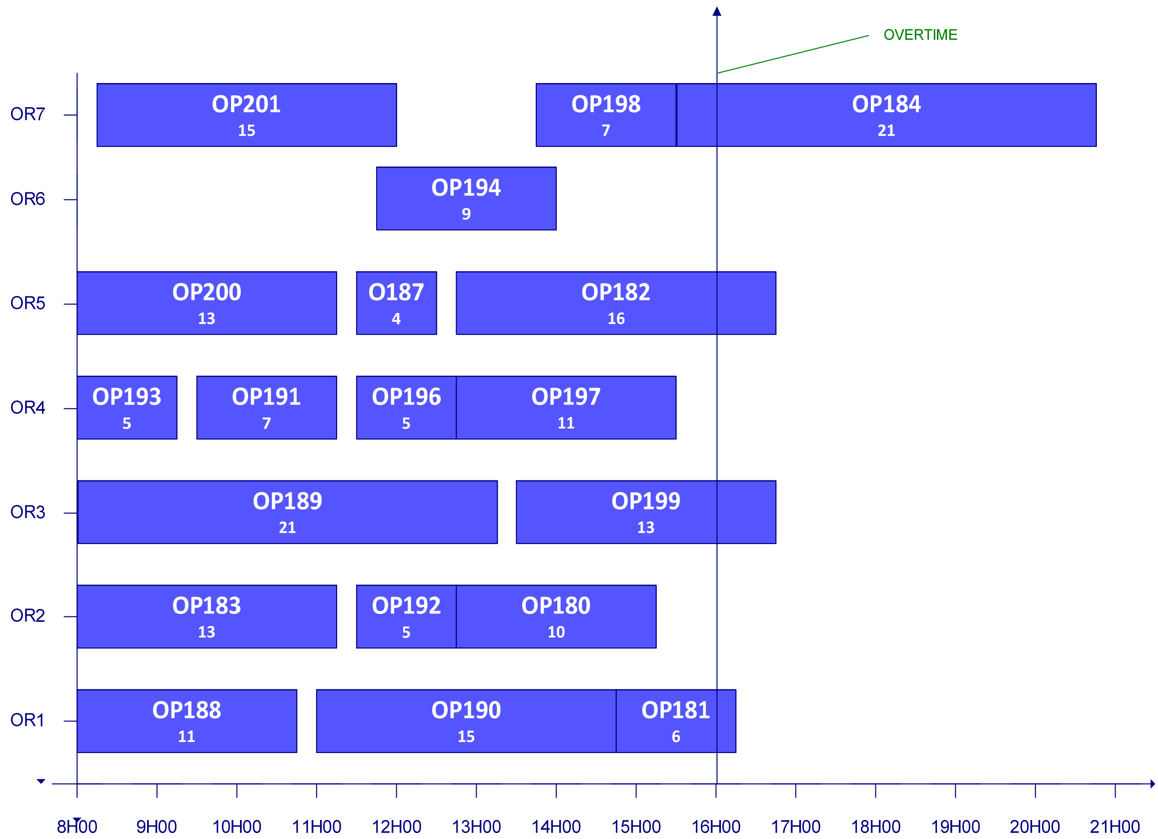

Figure 47. Hospital current scheduling for one day

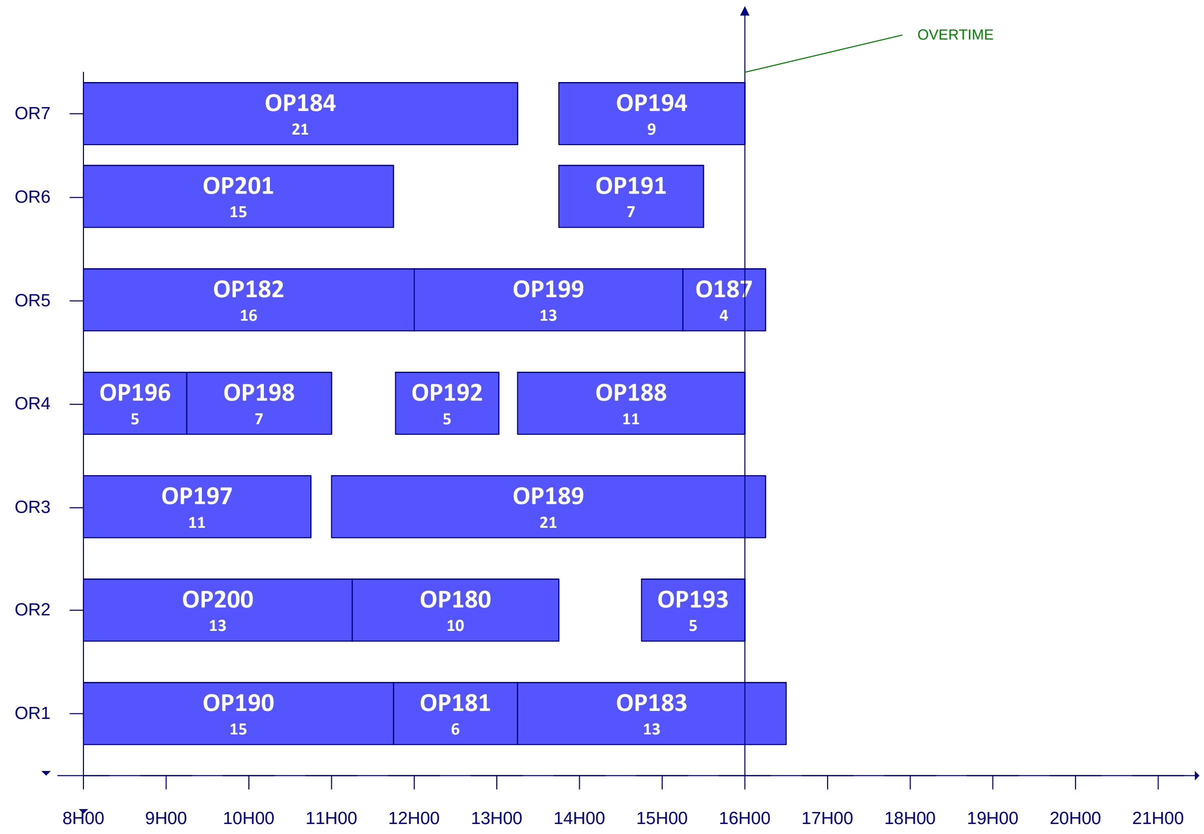

Figure 48. Proposed scheduling for one day

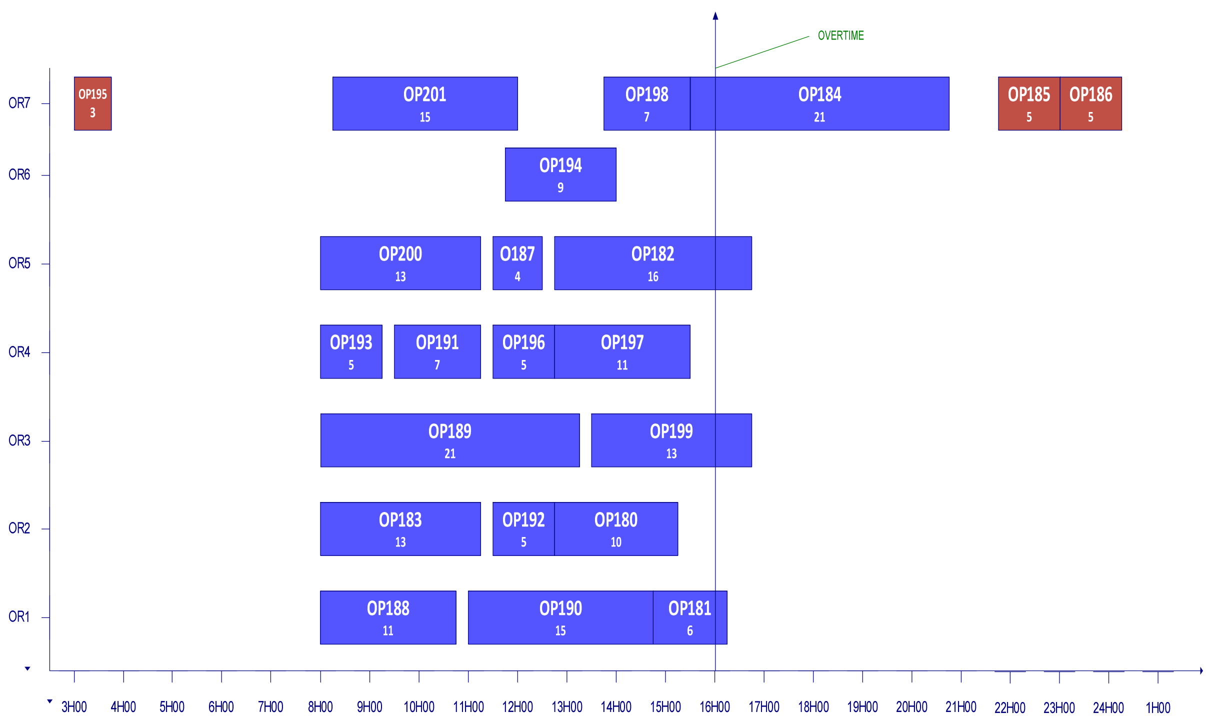

Figure 49. Hospital actual scheduling with the emergencies

2.3.2 Two days

We now consider at the same time to plan the surgeries over 2 days. For comparison reasons, we take into account the day previously considered and the one before, so a Monday and a Tuesday. There are 31 surgical interventions to schedule. Among them, 6 have to take place the first day and 8 the second days due to the availability of the surgeons. Seventeen surgeries can take place either the day 1 or day 2. A total of 17 surgeons operate during these 2 days. The Figure 50 and Figure 51 correspond to the current planning. The total cost is 29.820,00 €.

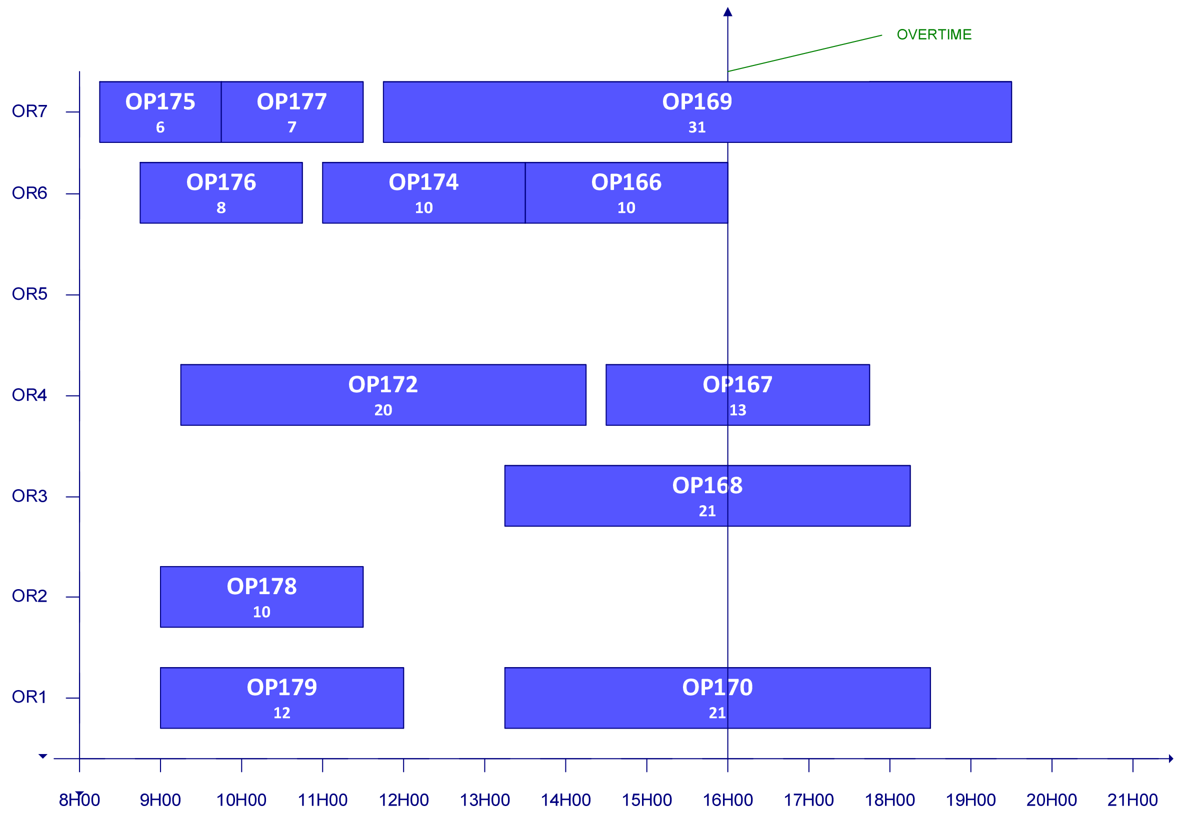

Figure 50. Hospital current scheduling for day 1

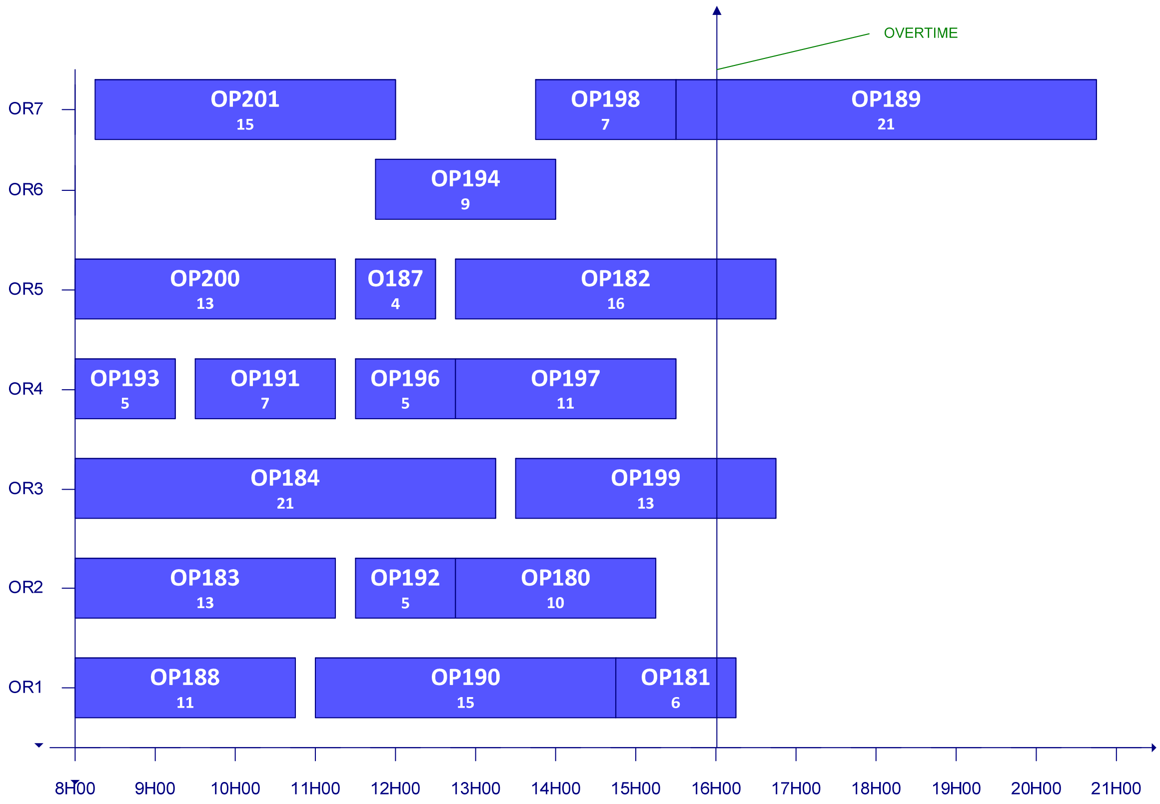

Figure 51. Hospital current scheduling for day 2

To solve this scheduling problem, the computer was running for 2 full days and we didn't get any final solution after this time. We therefore decided to run the program while asking to interrupt the execution when a solution was found. The Figure 52 represents the cost evolution of the solutions found while the computational time increases.

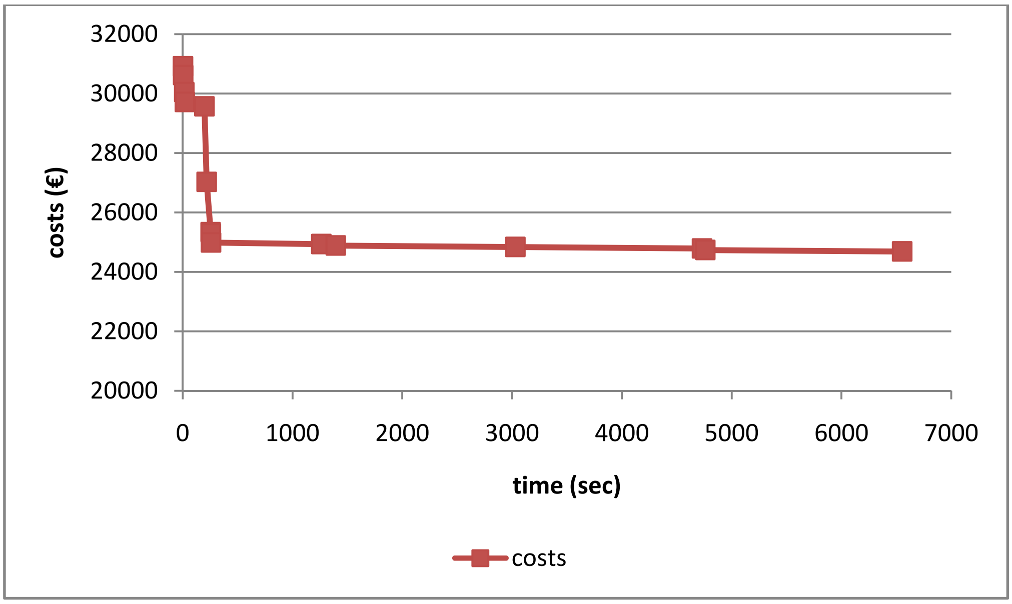

Figure 52. Evolution of the objective function with the computational time

The different solutions are improving during the first one thousand seconds run. After that time, the solutions differ only by the 50,00 €, which is the cost of one time unit of overtime.

The last solution we got is the 15th solution, with a cost of 24.240,00 €. This result, which is not optimal since the branch-and-bound exploration doesn't finish, represents a cost decrease of 18,7% compared to the current timetabling. The Figure 53 and Figure 54 schematize the planning for these days. As we are considering the planning and scheduling of the operations over 2 days at the same time, we can notice that some surgeries that were planned one day in the hospital current scheduling are programmed the other day. It is possible if the surgeons are available both days. The surgeries that are planned a different day compared to the current timetabling are displayed in dark blue for the day 1 (Figure 53) and in grey for the day 2 (Figure 54).

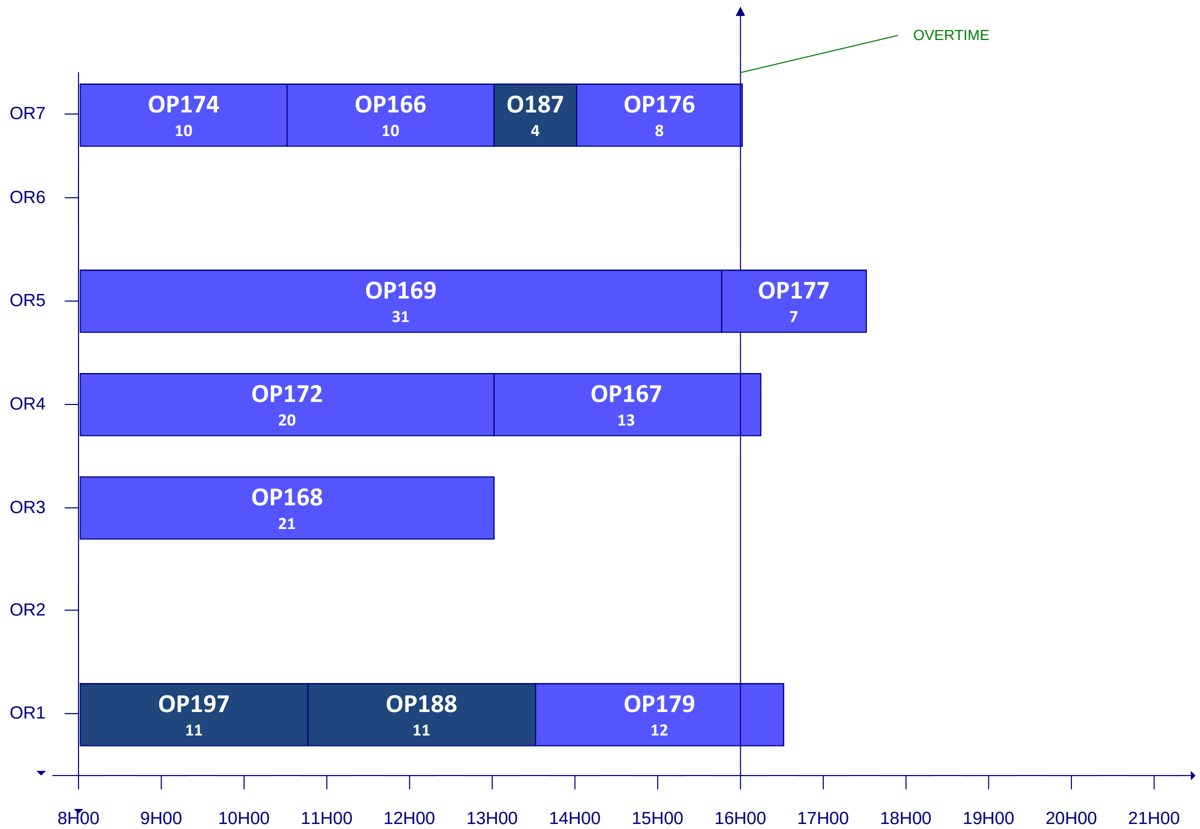

Figure 53. Proposed solution for day 1(the surgeries that were previously programmed the day 2 are in dark blue in the graphic)

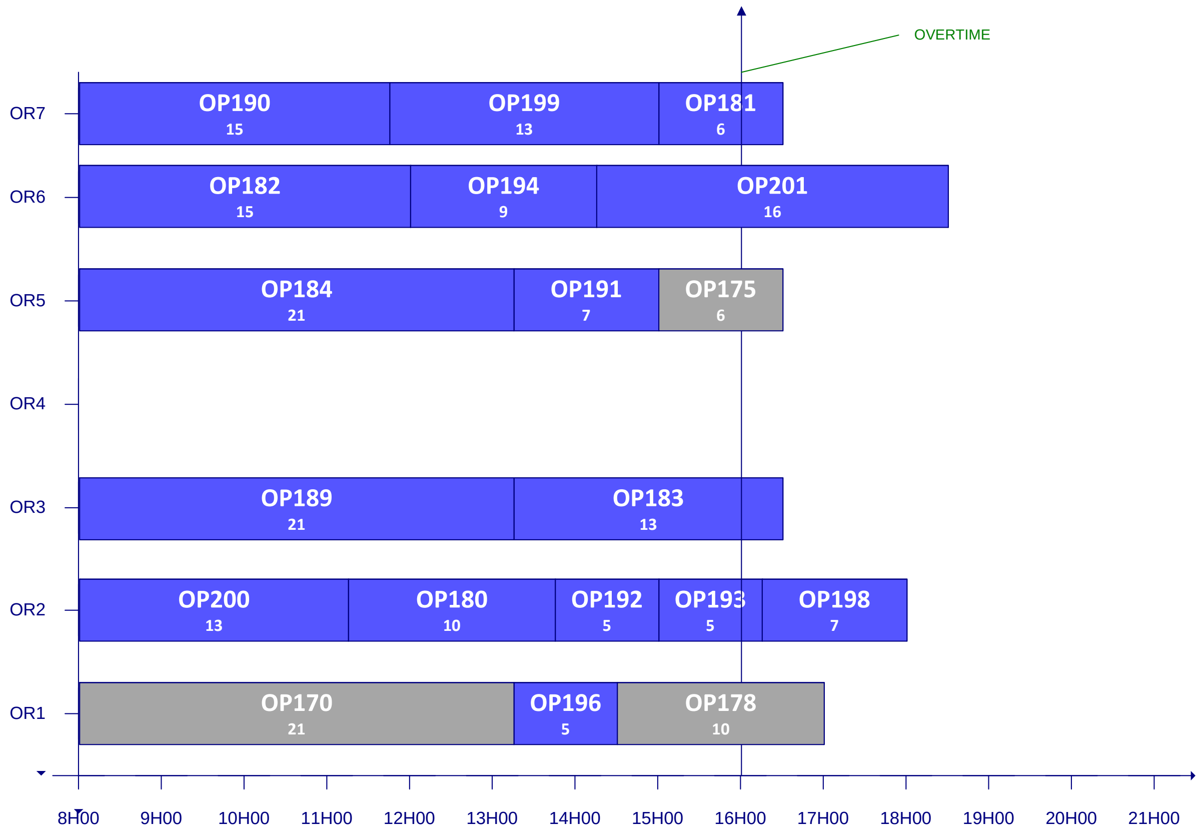

Figure 54. Proposed solution for day 2 (the surgeries that were programmed the day 1 in the original planning are now in grey in the graphic)

To consider the surgeries over 2 days allow smoothing the workload over the different days. This scheduling however doesn't take into account the emergency surgeries. There are:

- For day 1, 2 emergency surgeries: one at night and the other occurs during the day; the Figure 55 shows how these emergencies are currently integrated within the elective surgeries;
- For day 2, 3 emergency surgeries: one before 8 AM and two after 8 PM (as previously considered).

The Figure 55 schematizes how the emergency surgeries of day 1 were currently managed by the hospital. For the day 2, we refer to the Figure 49.

There is no problem to consider the emergencies in the proposed planning for day 2 since those one happen before or after the opening hours of the OR.

What about the emergencies of day 1, the emergency surgery that occurs after 8 PM can take place in any operating room. The other emergency (OP 173 in the Figure 55) happens at 11.45 AM. If the emergency can wait 1 ¼ hour, it can take place in the OR 3 at 1 PM; otherwise, it is needed to open an OR to deal with it. This solution will cause a cost increase but will be less expensive. The Figure 56 illustrates the proposed planning taking into account the emergencies. We program the emergency surgery in the room 2 since it is an orthopedic intervention and the room 2 is dedicated that week to the orthopedic specialty.

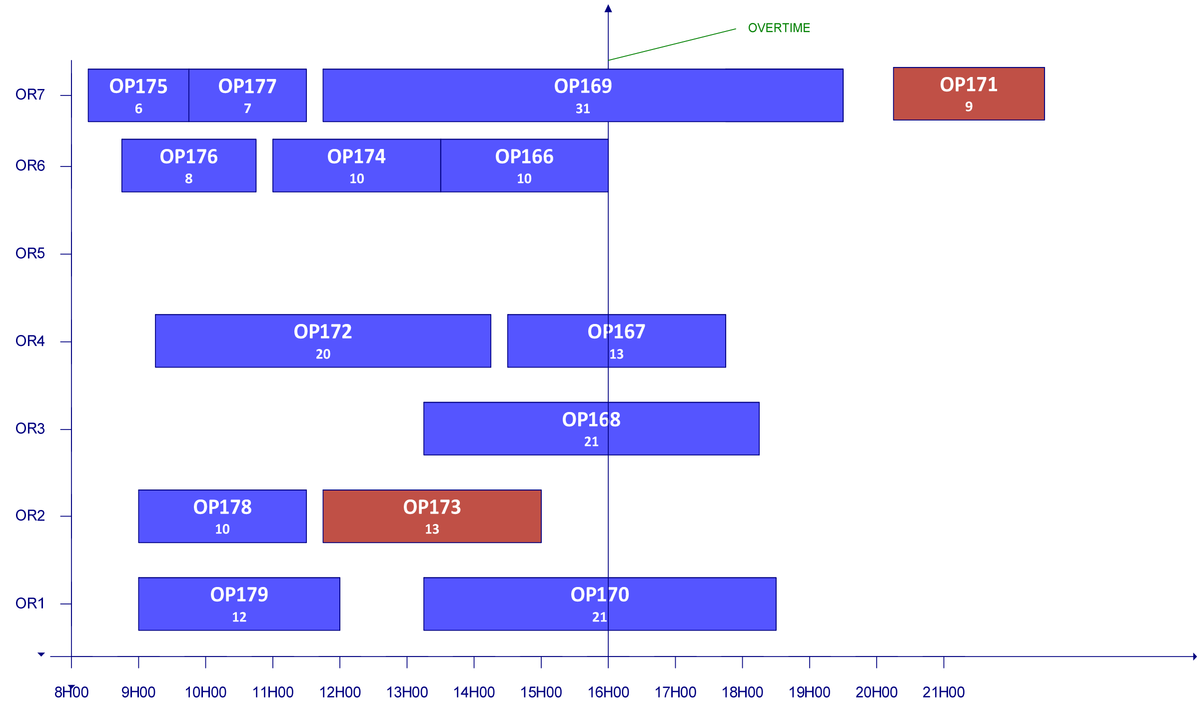

Figure 55. Current planning for day 1 with the emergency

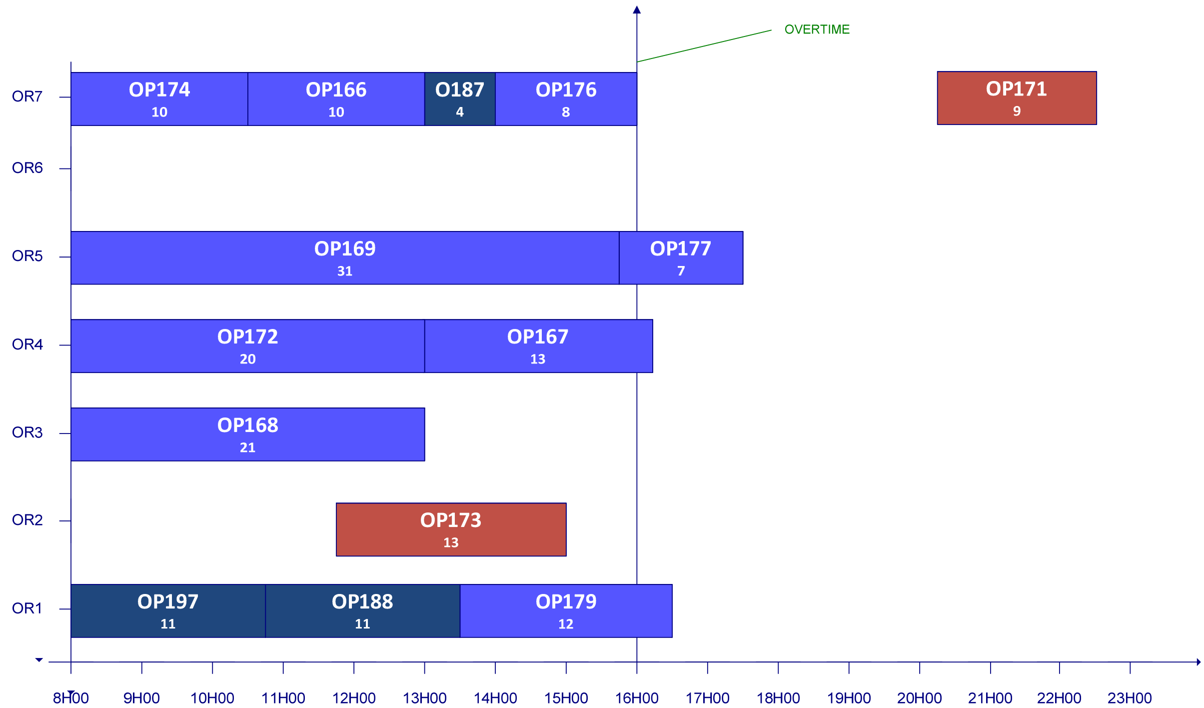

Figure 56. Proposed planning for day1 with the integration of the emergencies

2.3.3 Cost comparisons and observations

The Table 30 provides a comparison between the original planning of the hospital and our proposed solution. We use the indicators that we defined in the chapter 4 and we compare the costs of both plannings. Since our model doesn't integrate the emergencies, we also add the costs of the planning taking into account the emergencies that were added manually.

We can observe that the solutions proposed by the mathematical program are less expensive that the current timetabling even when taking into account the emergencies. We also notice that this difference becomes bigger when we plan over two days. Considering more days leaves more room to optimize the planning. The program minimizes overtime and rooms opening. As a result, the inactivity rate is also lower.

Table 30. Comparisons between the original planning and the proposed planning

one day

	originial planning		suggested planning	
indicators	**without emergencies**	**with emergencies**	**without emergencies**	**with emergencies**
nb of elective surgeries	19	19	19	19
nb of emergency surgeries	0	3	0	3
total nb of surgeries	19	22	19	22
activity hours	207	220	207	220
overtime hours	25	31	4	17
inactivity hours	42	42	21	21
elective surgery rate	100%	94,09%	100%	94,09%
overtime rate	11,16%	16,96%	1,79%	7,59%
occupation rate	92,41%	98,21%	92,41%	98,21%
inactivity rate	18,75%	18,75%	9,38%	9,38%
cost	15.530,00 €	15.830,00 €	14.480,00 €	15.130,00 €
cost decrease compared to the original planning			6,76%	4,42%

two days

	originial planning		suggested planning	
indicators	**without emergencies**	**with emergencies**	**without emergencies**	**with emergencies**
nb of elective surgeries	31	31	31	31
nb of emergency surgeries	0	5	0	5
total nb of surgeries	31	36	31	36
activity hours	376	411	376	411
overtime hours	66	156	36	128
inactivity hours	138	125	108	97
elective surgery rate	100,00%	91,48%	100,00%	91,48%
overtime rate	14,73%	34,82%	8,04%	28,13%
occupation rate	69,20%	72,10%	75,89%	78,35%
inactivity rate	30,80%	27,90%	24,11%	21,65%
cost	29.820,00 €	34.320,00 €	24.240,00 €	31.230,00 €
cost decrease compared to the original planning			18,71%	9,00%

However, the mathematical program is less flexible and a number of questions are raised:

- Scheduling of long elective surgeries: if we look at the Figure 51, we notice that a surgery is planned nearly at the end of the normal working hours and ends later than the overtime we allow in the mathematical program. This would never be proposed by the program. But why this happens? Was the length of the surgery properly evaluated at the time of the timetabling? Or was it a will of the surgeon? Would he accept our planning? This underlines the importance of a good communication while using a tool to program the surgeries. It also emphasizes that we use the realized data to establish the planning and we therefore know the real length of the surgery. When the head nurse does the planning, she bases herself on an estimated surgical time.

- Dedicated rooms to surgical specialties: the OR are managed with a block scheduling policy, dedicating the rooms to surgical specialties at some time. The mathematical program will therefore schedule a surgery to occur only in the appropriate OR. However, some surgeons have several specialties as urology and gynecology and they can plan the surgery in any of the rooms dedicated to their specialties. In addition, there are some “agreements” between some specialties that share easier the OR as the orthopedy and the cardiology. To take that into account, we allow for instance the orthopedic surgery to take place not only in the OR 4 but also in the OR 1 and 2. Doing so, however, we can be proposed a schedule that plans all the orthopedic surgeries in room 1 and 2 and no one in room 4, even when this one is dedicated to that surgical specialty. In addition, there is also a common practice that, when a surgical specialty has a high activity a particular day, it can operate in another OR in the unused block times of that other specialty. This practice is however left to the discretion of the surgeons and is difficult to model.
- Integration of the emergencies in the planning: so far, we observe little influence of the emergencies in the surgical scheduling. It sounded however to be one of the major problem in the OT. We have in addition no information about the different type of emergencies. The OT manager ranks the emergencies in three types: the emergencies that have to be taken care of at the time they happen; the emergencies that can wait until the end of the day and the emergencies that have to be taken care of within 48 hours. Only the first type of emergencies will cause disruption in the planning since the other can take place for instance any time during the closing hours. The percentage of urging emergencies is often low. All type of emergencies taken into account, the emergency surgeries represent in our data 7% of all surgical interventions. The percentage of emergencies to treat as soon as possible is therefore lower. Some studies show that these emergencies can represent 3% (Reymondon et al. 2007), causing minor perturbations in the planning.

The way we have modeled the planning and scheduling of the surgical interventions allows some extensions and would allow integrating for instance the precedence constraints linked to the type of surgery (infected versus non infected patients). However, by taking into account more elements, the problem will take more time to be solved. It is thus interesting to evaluate the performance of other methods to solve that program. As we underlined it at the beginning of this chapter, we model our problem as a RCPSP. Some efficient meta-heuristics have been developed to solve it and some of our colleagues are working on it (Roland et al. 2007). The idea is to use the genetic algorithm to solve this optimization problem.

The planning choice is important because it can serve as input to a MRP system to determine the quantities of materials needed to lead the surgeries over one week. The application of this principle is possible if a preference list is linked to each surgical intervention code, based on the same principle as the bill of materials. However, as we mentioned it previously, the materials consumption may vary from surgery to surgery, leading to what is called a stochastic bill of materials. The demand for materials is so impacted by two factors: the uncertainty of the surgical case and the uncertainty linked to the bill of materials. It is critical to reduce as much as possible these uncertainties to keep the cost of inventories as low as possible (Rappold et al. 2006).

2.4 Conclusion

The knowledge building of the chapter 4 showed us that the pharmaceuticals consumption of the operating theatre was different from the emergency rooms. The demand for pharmaceuticals in the OT follows some deterministic patterns generated by the planning and scheduling of the surgical operations. It is therefore needed to optimize this step before implementing an inventory management solution.

Most of the researches use an approach in two steps, the planning and then the scheduling of the surgical activities, which may lead to an infeasible timetabling. To avoid that problem, we modeled together the planning and scheduling phase as a mixed integer program. Our model allocates each surgical procedure an operating day, an operating room and a starting time considering the constraints of personnel, availability of the surgeons and dedication of the operating rooms. The way we model the problem however allow further extensions to take into account the precedence constraints between the surgeries (infected versus non infected patients), the preference of the surgeons and the availability of non renewable resources. Because of the size of the problem, we could only test our model to schedule one day and two days of the surgical activity. So far the results obtained show that the mathematical program gives better results on the indicators we identified. The following table provides the value for the performance indicators that were indentified in the chapter 4 and that we get for the 2 days of planning.

As we told in the introductory chapter, the reengineering project in the hospital we are working with is an ongoing project and therefore, all data are not available. What about the inventory management measure, no stocktaking study has been led so far in the operating room to estimate the current amount of inventory. A study done by (Migamba 2006) pointed up the problem of the multiple storage locations and amount of inventory kept in the OT of that hospital, underlining the fact that there is a need to review the inventory management policy. The study of the OR working pointed up the need to link the inventory policy to the planning and scheduling of the surgical interventions. At each surgical procedure corresponds a preference list. For a hospital with the same OT activity level, which has started to standardize the preference lists contrary to the hospital we are collaborating with, there are more than 7000 preference lists with an average of 70 different items on each (Di Martinelly 2006). There is therefore a need for a computerized and informative system to implement the MRP approach.

- ***Patient's perspective***

Objectives	*Indicators*	*Definitions*	*AS-IS*	*TO-BE*
Ensuring the patient's satisfaction	Number of patients	Number of patients who underwent surgery over a determined period	36	36
Ensuring the patient's satisfaction	Patient's satisfaction rate	Ratio between the number of patients satisfied by the service received and the total number of patients	NA	NA
Ensuring the patient's satisfaction	Patient's complaints rate	Ratio between the number of complaints and the total number of patients	NA	NA
Respect of the planning	Number of cancelled surgeries	Number of surgeries that were cancelled because not planned within x days	NA	0

- ***Financial perspective***

Objectives	*Indicators*	*Definitions*	*AS-IS*	*TO-BE*
Costs reduction and income increase of the care unit – OT	Costs	Costs linked to the OT activity	34.320,00€	31.230,00€
Increase of the number of surgeries	Revenue	Income generated by the surgical activity	Idem	Idem
Reduction of overtime	Personnel expenses	Costs of personnel (% of costs in normal hours)	134,82%	128,13%
Reduction of inventory costs	Inventory cost	Costs of inventory (holding costs and backorders costs)		
Reduction of the number of references	Number of references	Number of different items in the preference lists		

- ***Internal processes perspective***

Objectives	*Indicators*	*Definition*	*AS-IS*	*TO-BE*
Ensuring the efficiency of processes	Delay hours	Total delay hours for elective surgeries	NA	NA
Ensuring the efficiency of processes	Overtime	Total hours during which there were surgeries after the normal closing hours (16H00)	156	128
Ensuring the efficiency of processes	Delay rate	Delay hours/total opening hours	NA	NA
Ensuring the efficiency of processes	Overtime rate	Overtime/total opening hours	34,82%	28,13%
Optimization of OR management	Occupation rate	Activity hours/total opening hours	72,10%	78,35%
Optimization of OR management	Inactivity rate	Inactivity hours/total opening hours	27,90%	21,65%
Optimization of OR management	Activity hours	Total number of hours used by elective surgeries	376	376
Optimization of OR management	Inactivity hours	Total number of hours where the OR are open but during which there is no activity	125	97
Increase of the number of surgeries	Number of surgical procedures		36	36
Increase of the number of surgeries	Elective surgery rate	Activity hours/total operating time	91,48%	91,48%
Increase of the number of surgeries	Emergency surgery rate	Total time required by emergency surgeries/total operating time	8,52%	8,52%
Increase of the number of surgeries	Ambulatory surgery rate		NA	NA
Optimization of OR staff time	Overtime	Total hours during which there were surgeries after the normal closing hours (16H00)	156	128

- ***Learning and growth perspective***

Objectives	*Indicators*	*Definition*	*AS-IS*	*TO-BE*
Having personnel with good skills and satisfied	Personnel satisfaction rate	Ratio between the number of employees satisfied by the current working organization and the total number of employees	NA	NA
Having personnel with good skills and satisfied	Personnel turnover	Ratio between the total number of employees who left during the year and the total number of employees.	NA	NA
Having a personnel with adequate skills	Skilled personnel rate	Ratio between the number of employees who have received training and the total number of employees	NA	NA
Appropriate workload	Overtime	Total hours during which there were surgeries after the normal closing hours (16H00)	156	128

Chapter 6. Conclusion

The objective of our research is the development of a modeling framework that permits decision makers to reengineer and evaluate the hospital supply chain. This research was first motivated by a strong collaboration with a Belgian hospital of 900 beds that is currently reengineering its logistical activities. The managers of this hospital intend to build a new logistical platform to group the clinical pharmacy, the sterilization and purchasing services in a same location. These units are currently in separated areas.

This reengineering project implies changes in the current practices and has an impact on numerous resources. Because of the impact on the health care organization, it is needed to assess the current system, to diagnose the weaknesses and to evaluate the solutions before their implementation. We therefore develop a methodology to provide guidance to lead this project. The suggested framework gives support to build a knowledge model based on the ASDI methodology and enriched with our value and performance definition. The knowledge model is aimed at understanding the working of the system, identifying the critical activities, defining the performance indicators to assess the system based on metrics in accordance with the value system and describing processes and management rules.

The value and performance definition is based on the assumption that the different stakeholders of the hospitals, medical personnel, management, patients and funding organizations, don’t share the same perspectives. It is therefore needed to have a common understanding of the strategy and its translation into objectives to monitor the hospital and to reach the expected performance. The building of the value and performance definition is based on a five-step approach.

The first step of the value and performance model is the Porter’s strategic analysis. It highlights the influence of the environment on the strategy adopted by a hospital. This analysis showed us that the focus on the supply chain activities was a good way for hospitals to satisfy their mission, providing care of quality while keeping costs under control, whatever the strategy they want to pursue.

The second step, the Porter’s value chain, emphasizes the links existing between the hospital main value chain, the care creation, and the clinic pharmacy. It helps us to emphasize the links between the different value chains and to select the processes to analyze in more details.

The third phase, the processes description, is made through logical diagrams and is concomitantly led with the value chain analysis. It provides the user with more insight into the working of the activities and their chronology, the identification of the different responsibilities and of the weaknesses in the current working. It also serves as a good communication tool, based on a simple formalism understandable for most actors. The logical diagrams make it also easier to implement the changes by involving the stakeholders in the project and by objectifying the practices.

The fourth phase is the objectives translation. Starting from the general objectives deduced from the strategy, we use the connectance diagrams to identify the variables that have an influence upon these general outcome objectives. These variables define the specific objectives, the performance drivers. For these last, we identify the different processes implied and we point out the responsibilities thanks to the logical diagrams.

The last step is the building of the scorecard using the balanced scorecard framework. The objectives identified in the previous step are linked to the different axes of the balanced scorecard and the cause-effect relationship is verified to ensure that all objectives are going in the same direction as the strategy. The performance indicators for each objective come from the literature and are selected and validated by the actors.

This methodology to gather the knowledge and to organize it was successfully applied to the Belgium University hospital with which we are collaborating. We described the pharmaceuticals dispensing processes of the two medico-technical units of concern, the emergency rooms and the operating rooms. This step allowed us to diagnose the current working of these processes. We identified four main weaknesses in the current pharmaceuticals dispensing. Some activities are executed several times leading to additional personnel costs and to increased risks of errors. The poor integration of the information within a unique system raises problems as traceability, safety in the dispensing of the pharmaceuticals and financial losses due to the non billing of the pharmaceuticals. The pharmaceuticals management policy and practices lead to overstocking of some items and backordering of other; the nurses are overwhelmed by the administrative tasks of the inventory management. Finally, the current physical design induces problems in the distribution since the units are located in separate areas.

Before proposing solutions and implementing them, the current situation had to be quantified by measures. It supposes that the objectives are already defined. Starting from the literature review, we highlighted the general objectives of the hospital, which give the general outcome measures. We used the connectance diagrams and the knowledge acquired through the logical diagrams to determine the specific objectives for the units, the performance drivers for the OT and for the ER. The strategy map helped us to ensure that the objectives are taking into account the different stakeholders perspectives and that the different objectives provide a tool to the management to pilot the hospital towards the achievement of the strategy.

To answer the questions raised by the reengineering project about the supply chain management, we developed an optimization tool of the management of medical products flow while taking into account the patient's flow. For the emergency room, we evaluated the implementation of an automated dispensing system and we suggested applying a two-echelon inventory management model to control this new system. It is based on the newsboy model and provides us with the quantities to keep in stock, their location (central pharmacy or emergency rooms) and the quantities to supply each period in the system. The automated dispensing cabinet answers to most of the problems that were identified as the introduction of a unique information system, the simplification of the processes to delete the tasks that were redundant and the setup of an appropriate inventory management policy to control the new system. The implementation of such system provides improvement on all the indicators identified.

Concerning the operating theatre, the system could not be implemented the same way. The inventory management policy proposed was not suitable since the demand is deterministic. We therefore suggested a two-step approach. We determined the planning and scheduling of the surgical operations using a mixed integer program. Our model allocates each surgical procedure an operating day, an operating room and a starting time considering the constraints of personnel, availability of the surgeons and dedication of the operating rooms. Because of the size of the problem, we could only test our model to schedule one day and two days of the surgical activity. So far the results obtained show that the mathematical program gives better results on the indicators we identified. The resulting planning can serve as a basis for a MRP approach based on a stochastic bill of resources.

The performance indicators we defined in the first step serve to assess the proposed solutions. The proposed approach ensures that the suggested changes improve the working of the pharmaceuticals supply chain and contribute to the global interest of the hospital.

Through the application of the framework to a concrete case, we faced some problems, especially during the knowledge modeling. The definition of the value and performance model was not easy-going and required the implication of the different hospital actors. The strategy of the hospital is often not well defined and the strategy translation into the different objectives requires a good knowledge of the system. Besides that, it is necessary that the different stakeholders communicate to share a common vision. For that point, we notice that the use of the logical diagrams in the approach really ease the communication between the actors and objective the current practices.

Concerning the actions models, we could successfully adapt and apply industrial models to the hospital while taking into account as much problem characteristics as possible. The adaptation of the inventory management model allowed us to determine the quantities to provide and to keep on storage at the different locations. The computational speed will allow re-computing the policy value to take into account changes in the demand and in the pharmaceuticals prices. In the inventory model, it could be interesting to take into account the volume of the products when this information is available, since the space available is often limited in hospitals. It could also be interesting to see how the proposed policy varies if the distribution settings changes because we had these settings as a constraint. What about the operating rooms, the optimization model can be improved by taking into account the preference of the surgeons and the precedence constraints between the surgical operations (infected versus non infected patients). To solve this problem, heuristics methods need to be developed to provide solutions within an acceptable amount of time. Doctoral researches are currently undergoing on that subject (Roland et al. 2007). The planning and scheduling of the operating rooms provide the necessary information to apply a MRP approach to manage the pharmaceuticals. The inventory management policy still needs to be defined to provide the adequate service level. The performance of the MRP system will be highly dependent on the variability in the demand: the uncertainty of the number of surgical interventions and their type and the uncertainty in the products consumption (Rappold et al. 2006). It is therefore needed to reduce as much as possible the uncertainty by standardizing the preference lists and to build plannings that are robust.

During this doctoral research we were also made aware to the problematic of data in the health care sector. The data collection is indeed not easy due to the multiple information systems existing in a health care institution and that are often “home-made”. Requests in such database are often partial. The multiple databases that co-exist in the hospitals are also a source of multiple recording errors, don’t ease the traceability and make also more difficult errors tracking and corrections. This situation is made worst by the problematic of the privacy around the patients’data.

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FOLIO ADMINISTRATIF

THESE SOUTENUE DEVANT L'INSTITUT NATIONAL DES SCIENCES APPLIQUEES DE LYON

NOM : DI MARTINELLY (avec précision du nom de jeune fille, le cas échéant) Prénoms : Christine Jeanne Marie-Laure Ghislaine	DATE de SOUTENANCE : 19 mai 2008
TITRE : Proposition of a framework to reengineer and evaluate the hospital supply chain	
NATURE : Doctorat Ecole doctorale : informatique et information pour la société Spécialité : Génie Industriel	Numéro d'ordre : 2008-ISAL-0029
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RESUME :

L'objectif de notre recherche est le développement d'un cadre de modélisation pour permettre aux décideurs de réorganiser et d'évaluer la chaîne logistique hospitalière. Notre démarche se déroule en plusieurs étapes. Tout d'abord, nous réadaptons la définition des concepts fondamentaux de la valeur et de la performance dans le contexte de la chaîne logistique hospitalière. Nous proposons ensuite une approche pour aider les preneurs de décisions à mener un projet de réorganisation dans le domaine hospitalier et en particulier la réorganisation de la chaîne des produits pharmaceutiques en prenant en compte le flux des patients.

Le cadre de modélisation proposé sert de guide dans l'élaboration d'un modèle de connaissance basé sur la méthodologie ASCI et enrichie de la définition de la valeur et de la performance. Le modèle de connaissance a pour objectif de faciliter la compréhension du fonctionnement du système, d'identifier les activités critiques, de définir les indicateurs de performance servant à évaluer le système sur base de mesures reflétant de manière adéquate le système de valeur de l'hôpital. Le modèle de connaissance fournit également une description des processus, des règles de gestion et l'identification des ressources.

Lorsque le modèle de connaissance a été élaboré, il est possible de développer un outil d'optimisation du flux des produits médicaux tout en considérant le flux des patients. Les indicateurs de performance définis lors de l'élaboration du modèle de connaissance servent à évaluer les solutions proposées. Différents tableaux de bord équilibrés sont proposés pour apprécier la performance des processus considérés. De la sorte, l'approche que nous avons développée permet de s'assurer que les changements suggérés améliorent le fonctionnement de la chaîne logistique pharmaceutique et contribue à améliorer la performance globale de l'hôpital. Ce modèle a été validé sur des données provenant de l'hôpital belge avec lequel nous collaborons.

MOTS CLES : gestion hospitalière, modélisation, optimisation, performance

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