DESIGN OF THE EMERGENCY SERVICE PRODUCTION IN A PUBLIC HOSPITAL

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DESIGN OF THE EMERGENCY SERVICE PRODUCTION IN A PUBLIC HOSPITAL[1]

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Summary

For a major public hospital in Santiago we did a design for the Emergency service production, including its implementation, which we synthesize here. Analyzing the data of production and performance of the hospital´s Emergency Department we concluded that patients classified as M2 and M3 by a Triage use more than 90% of the use of resources. Therefore, the design focuses on these patients, since they are also a priority due to the severity of their condition. To order the workflow, which was mixed and confounded with the rest of the patients, production lines were segregated for the M2 and MC3 patients. For such lines to be orderly and logical, the physical space was remodeled by means of an architecture project. This resulted in a well-defined workflow in which patients go through locations, identified by signals, where well specified medical actions are performed and governed, in some cases, by medical protocols. Then they go from one step to the following under well-defined criteria and their situation is known at all times. This makes a huge difference in terms of physical organization; elimination of delays due to "loss" of patients, ensuring that the most seriously ill patients are perfectly identified and have no risk of delayed attention; and better and more effective use of the time of doctors and nurses, including better coordination with exams services. Theory and international experience support such design, since specialization is favored by concentrating a group of professionals in situations with less variety, facilitating coordination and increasing productivity. In a similar approach an important hospital such as the one of Stanford University decided to implement split flows in its emergency in order to accelerate the flow and increase productivity[3].

New workflows were implemented in June and July 2017. Comparison of patients' LOS from July to August, shows a decrease after implementation of about 20 % and with a decreasing tendency. Also a comparison with 2016 same months was made showing up to 50% reduction. But most important, Emergency Department professionals, who were reticent at the beginning of the implementation, were quickly convinced that the flow provided more order and helped them in their work.

In addition to the design of the flow, protocols were developed for medical treatment of the most frequent disease, in this case Cardiology, establishing which medical variables to measure, with tests and actions to execute according to their values. Cardiology Protocol was successfully implemented. Also, flow support services, such as exams and inter consulting, have been improved to reduce service time and avoid delays in the flow.

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[2] Both authors are associated with the Public Systems Center and led a team of medical professionals composed of MD I. Paredes and Nurse A. Moreno, and engineers and MS, including A. Gonzalez, B. Arce, M. Cortes and R. Barros, which performed the work reported here. There was also active and valuable participation in the project of HSJD medical professionals, including MD Margarita Samame, Hospital Director, MD Rodrigo Riffo, Emergency Head, and Nurses L. Vega and S. Hernandez; we are deeply grateful for their support.

[3] Urgent Matters, Stanford Health Care (2017)

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1. Design problem

The modern literature of service design emphasizes the design of the production of the service itself, in contrast to the traditional emphasis on the design of the management of the same. In complex services, such as health, this means to determine actions to be performed on the patients and how to put them into practice. This is a major challenge, since we must determine the above for each patient in particular, given the varied symptoms that may be present, which is particularly difficult in an emergency, where patients have a single point of arrival. That is the flow that each patient should follow and the actions to be carried out in each part of the flow must be determined. This is impossible to define a priori, so the solution is to design generic flows with variants allowing to dynamically determine what to do along the flow with particular patients, including:

i. Determining flows differentiated according to type of patient according to an appropriate classification; a fairly widespread example of classification is the one done with a Triage, which identifies, for example, critical patients who must follow a workflow that takes care of the severity of the patient's condition.
ii. Protocols which guide the actions within each stream and, possibly, for groups of patients within each stream
iii. Criteria for allocating available resources within each stream, such as doctors, nurses, beds and exam services
iv. Criteria for end of service

In this paper we describe a design as the above for the emergency of a large public hospital in Chile treating up to 5000 pacients per month. Such hospital uses a Triage in its emergency that discriminates very ill patients for urgent treatment; but for the rest of the patients only determines a priority of attention and there is no well-defined flows for them, generating problems of quality of care, delays and inefficient use of resources. This work describes a formal approach, with an engineering foundation, to design flows for groups of patients who should be prioritized and consume more resources.

2. Conceptual Framework

Relevant theories and approaches for the design framework we propose are reviewed in this section. Also a reference design architecture is presented.

2.1. Modularity and Platform Design

We now review the ideas of **Modularity and Platform Design** that have originated in designing physical products and manufacturing processes. When adapted to services they partially cover the service design problem we defined in the Introduction. In order to give a context in defining the service design scope of Modularity and Platform Design, we present our view of the general components involved in such design. Model in Figure 1 shows such components of a business design using a simple flow representation[4], which is inspired by the regulation model documented in several publications[5]. The main component behind the design problem related to Figure 1 is "Product or service production", which generates a good and/or service that is demanded by certain customers. The design of this component includes the design of the **physical product/service** that is provided to the customer and of the **production processes**— manufacturing and others— that are required to produce it. These two designs are in many cases related, since an adequate physical product/service design may simplify production processes design and allow for more flexibility in the offerings. In fact, one of the key ideas of Modularity is to design physical products/services by assembling components –using predefined interfaces- that are common to many of them. Clearly, this type of design determines the production processes necessary to provide products/services. The challenge of production design in complex services is that must be continuously adapted to demand´s dynamics, as opposed to manufacturing where the design is more stable.

Model in Figure 1 makes it clear that we also have to design the "Management activities", from business overall architecture and management processes designs to information system design, which should be consistent with the "Product or service production" just presented. The last component of the model in Figure 1 is "State update and reporting", which receives information about the transactions occurring in the other components, determines their current situation and feeds it back to the interested parties. It

[4] Barros (2000, 2004, 2016)
[5] Barros (1990, 1991, 1993, 1994a, 1994b, 1995, 1996, 1998)

corresponds to the information systems data bases and reporting of any business, and is obviously an object of design. However, as we will argue later, it is a consequence of the other components' design.

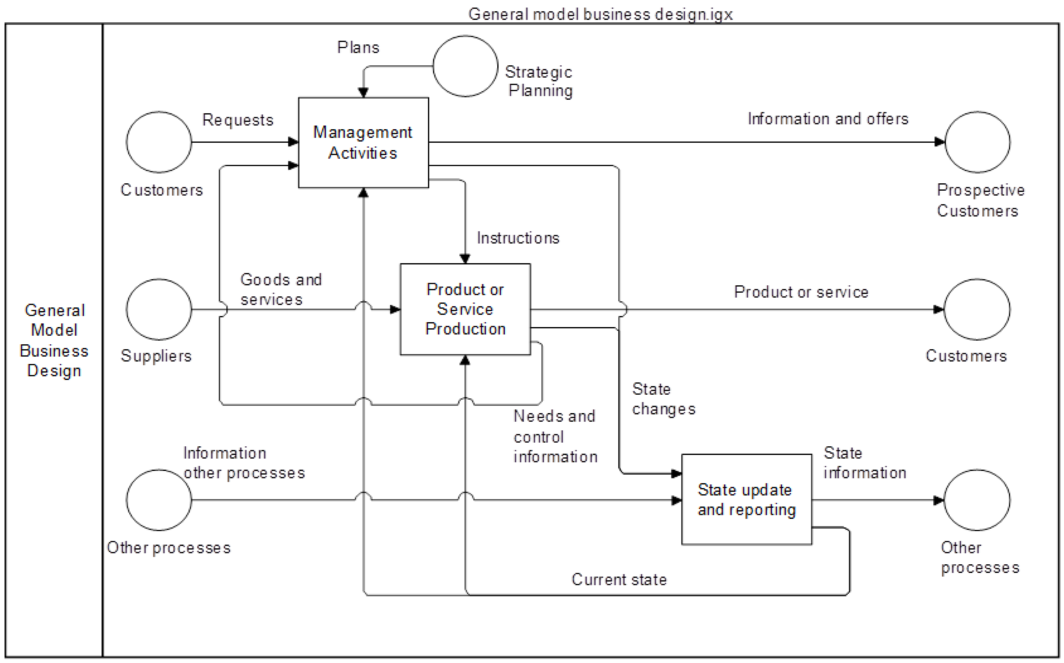

Figure 1: General model for Business Design

The ideas of Modularity and Platform Design we will review clearly concentrate on a partial business design —physical product/service and production processes—, but such ideas are more useful if integrated with other more systemic approaches. The presentation will be oriented to services where there is parallel production and consumption, as it is the case of healthcare, airlines, banks, cruise services, logistics, and department stores, among others. In some of these cases the idea of **coproduction** is also present, in the sense that the customer actively participates in the production of the service. In this context, Modularity "is the degree to which components of a system can be separated and recombined to create a variety of configurations without losing functionality"[6]. For example, in hospital services the usual design is to have modules for emergency care, ambulatory outpatient care and hospitalization inpatient care[7] services. Then a particular physical service is established dynamically, according to need, for a patient, which define the sequence of actions that will be performed over him by the different

[6] Pekkaninen & Ulkuniemi (2008); Dorbecker & Bohman (2013)
[7] Meyer, Jekowsky & Crane (2007)

modules. For example, a patient enters by emergency care and it sent, once stabilized, to hospitalization inpatient care, where he will have further treatments until it is discharged. This is further complicated by the fact that there are other modules —beds, surgical facilities, exams performing, procedures, etc. — that provide very specialized services that are activated according to need. Hence the flow of a patient can get very messy and good protocols are needed to coordinate the different modules involved, so that whatever the patient needs is provided on time and with the required quality. This is a very difficult problem and most hospitals do not have a good design to define, manage and control the flow. For this an approach called **case management** has been specialized to hospitals to provide such Capability[8]. In hospitals the **design of the physical service** involves the medical practices that are defined for each health problem, which the case management approach tries to explicitly design by using Modularity ideas. The production process design has to do with managing the patient flow by means of good practices and IT supporting systems. For example, monitoring the state of each patient, in time/space and also the medical variables relevant to his illness, to be able to timely act when necessary; this may include, as we will see latter in our patterns, the use of intelligent tools that, for instance, predict a possible patient's crisis based on his state and BI models developed from historical data. In most hospitals, this process is poorly defined and executed based only on the experience of medical professionals. Hence there is here an opportunity to improve many services by good production processes design, which has been severely overlooked in practice. We can observe that to the two related design problems just described, one can add a third design element, which is organization design, that can also be modular[9], and also present as functional components[10]; for example, specialty departments in a hospital: neurosurgery, pediatric, geriatric, heart disease and the like.

An interesting case that exemplifies the use of Modularity is the one of mental healthcare in Holland[11]. One relevant detail of this case is the definition of bundles for services of this type. We give a summary of one bundle for this in Table 1.

One of the consequences of very flexible modular arrangements is the possibility of generating new services in a very dynamic way, in the idea of mass customization, that are able to meet an heterogeneous

[8] Meyer, Jekowsky and Crane (2007)
[9] Pekkarinen and Ulkuniemi (2008)
[10] Voss and Hsuan (2009)
[11] We present a summary of the structure; full detail in Soffers et al.(2014)

demand[12]. Such an idea has been made feasible by a **Platform Design**, which has been defined by Meyer, Jekowsky & Crane, as an "specific set of service functionality —delivered in human or computer form, or more typical, some combination thereof— that is used across multiple services or the procedural connections that bridge and link specific sets of service functionality". These authors have applied above ideas to health services using case management to structure such service in two types: Inpatient Care and Outpatient Care. Then for each type they have designed the subsystems, composed of processes, human actors and computer systems support, necessary to manage cases, by defining the actions to be performed over the patients (personalized service) and coordinating his workflow by transferring information, by means of IT systems, along the line.

Bundle	Module	*Component*	Description
Health-related care	Psychiatric care	*Monitoring* Done by Care Person (CP)	This is a part of care everyone gets.
		Scaling up *Intensify care* *Crisis intervention*	When a patient (might) become(s) unstable, higher level CPs are involved.
		Education of thirds	Concerns educating and supporting the patient's family and friends, to create understanding of the patient's situation.
	Medication care	*Long-lasting medication* Collected at pre-set times	Called 'depot', this medication (usually) lasts several weeks.
		Regular medication *Directly from pharmacy* *From CP in weekly doses* *From CP in daily doses* *Collected at pre-set times* *Distributed at pre-set times*	Only people living off the terrain receive the medication from the pharmacy. Daily and weekly doses are always collected at the CPs office at pre-set times. Collecting/distributing happens at three pre-set times during a day
		If-needed medication Controlled by patient Collected at pre-set times	Medication for when a patient feels anxious or otherwise thinks some more medication

Table 1: Modularity in a health case

[12] Voss and Hsuan (2009)

Another interesting way to define bundles of modularized services is the one proposed by Blok et al.[13]. They define basic modules that are common to all services, modules that can reconfigured for different segments and modules that can be customized at the individual level, as differentiated above. They apply their ideas to the provision of services for the elderly in a real case in Holland, giving details about the design; for example, a basic service is living form; a configurable service is personal care with many variants and alternatives from which to select; and a customizable service is health related care.

Customization of services by using configurations of predefined components, as the mental health example given above shows, is a way to provide a service dynamically adapted to the customer.

The expected benefits of using Modularity on the design of a business are as follows:

- Unique modules that encapsulate advanced practices and are replicated along different business lines provide a competitive advantage that it is difficult to copy; for example a standardized logic based on medical variables to prioritize patients in waiting lists for attention by specialists that is used by all hospitals in a public network[14].
- Modularity allows dynamic customization and facilitates new product development, as shown in the health services examples above.
- Modularity favors standardization oriented to improving efficiency, as in medical specialty departments in hospitals.
- Modularity favors, in some cases, the centralization of services shared by several service lines, thus generating economies of scale; for example: exams, surgery and other services in hospitals
- Modularity also favors outsourcing, since the formal definitions of components and their interfaces facilitates the selection of what can be outsourced and the definition of how is to be implemented[15].

As described, Modularity concentrates on the physical product/service design, defined before.

[13] Blok et al. (2014)

[14] A case of this type which develops such logic is included in Barros (2017)

[15] Sheng, Wang and Sun (2012)

2.2. Evaluation Theories and Methods

Approaches to evaluate, and also to justify in advance certain designs, are management and economic theories. This subject was introduced by Barros[16], and it is treated in detail in other publications[17], so we only give a brief summary here.

First, we review **coordination costs and structures**. The coordination cost is one of the components of the production costs of the economic theory of production—together with the materials, labor, and several others—which increase at a rate greater than linear in relation to production, as a company grows; they are affected by diseconomies of scale due to the complexity of management inherent to the large size of an organization.

One can induce greater coordination in an organization by various means, which produce different cost effects. They are coordination mechanisms that come from disciplines, such as organizational theory, economics, operations research, IT, and management in general. Among others, we can mention rules, hierarchy, planning, collaboration, and the elimination of relationships that need to be coordinated. Several of these mechanisms can be boosted with IT. The problem is, then, to choose a right coordination level by using economic evaluation; for example, if we currently have a low level of coordination, up to which level it is convenient to increase it? It is also a relevant question when a company is decomposed into separate smaller components to eliminate relationships and avoid coordination. The answer to this question has to do with the visible and hidden costs that are induced by a certain degree of coordination. The obvious costs associated with coordination are those relating to the method used to coordinate. To increase coordination, more personal and more time, increased processing of information and more hardware, software, and communications to support coordination are required. If this were the only cost, there will be no justification to coordinate. However, there is a cost little visualized in practice, which is the one associated with the consequences of not coordinating. Poor coordination implies that the organization's resources are used in a manner much less than optimal. In particular, slack resources[18] appear, which are the ones that are assigned implicitly or explicitly to absorb the consequences of the lack of coordination. For example, more resources than necessary are needed in hospitals when

[16] Barros (1990, 1991).

[17] Barros (1995, 2000, 2004).

[18] Gailbraith (1977).

programming of operating rooms is not properly done[19]. Then, the choice of an adequate level of coordination becomes an economic issue: to balance the cost of coordination with the cost of the consequences of not coordinating. These costs move in opposite direction when the degree of coordination is increased.

There is another option to manage coordination costs, which is to split a service into smaller units to make them operate in a relatively independent way. This idea is equivalent to the classical divisionalization exercised by many large companies in the world. This clearly simplifies coordination and reduces costs associated to produce many different services in the same facilities. But, it may increase slack resources due to the challenge to maintain capacity fully occupied, due to demand restrictions, and duplication of resources that could be shared. For example, in hospitals, care is divided into lines of emergency and outpatient and coordination would be minimized if each line had all resources in hospitals in hospitals beds, surgery, exams and other services - needed, but this would imply a partial use of such resources due to variability of demand; that is why it is common for emergency and ambulatory to share such resources for their best use, which creates a serious problem of coordination that it is not well resolved in public hospitals. This problem originates one of the most important challenges in the design of the architecture of an organization's services and must be attacked explicitly and not resolved by trial and error, as in the public health.

Another evaluation approach is agency costs. In **Agency Theory**, the owner of a company or his representative is called the principal and the subordinates are the agents[20]. This economic theory recognizes that the assumption behind the theory of the firm, that it maximizes utilities, is too restrictive to analyze the behavior of its managers. The agency theory proposes the alternative vision that a company is a set of related contracts among individuals with their own interests. Put another way, an enterprise is a set of agency contracts, by means of which a principal (entrepreneur) hires agents (employees) to perform a service for him or her. The assumption of behavior that this theory makes—possibly more realistic than the one of the traditional theory of the firm—is that an agent, to maximize his individual utility, prefers less work and more rewards and that does not care about the welfare of the principal or other nonpecuniary benefits.[21] From these ideas, costs that the traditional theory of the firm does not

[19] Barros (2017)
[20] Arrow (1985)

[21] Jensen and Meckling (1976); Jensen (1983).

consider can be identified. Firstly, we have the costs that result due to discrepancies among the objectives of the principal and those of the agents. For example, consider the Ministry of Health, where the Minister is the principal representing the owner, which is the State, that hires doctors to provide health services. The production of such services will increase as doctors make more effort. The question is what is the optimal contract in terms of remuneration? First, assume a fixed salary. The assumption of agency theory implies that doctors would avoid much work and would produce the amount of services that would allow them a reasonable effort. An alternative is to give physicians an incentive associated with its production. Then, the doctors maximizes their utility by choosing the level of effort in which their marginal cost (for extra effort) equals its marginal revenue. Even with this incentive, the level of production can be less than what the main expected. But, there are another set of costs that depend on the degree of decentralization. Here, we have information processing costs that include the information necessary for the principal to make decisions about agents' behavior, which increase as decisions are more centralized. Also, opportunity costs arise due to lack or erroneous information for the decision makers, which increase as decisions are more centralized. This is very simplified summary of this theory, but it should be clear that several different costs should be considered when deciding on decentralization of activities and the methods that are used to align agents with the objectives of the principal.

2.3. Service Design Architectures

We start from the model of Figure 1 that is detailed to identify the different components that are subject to design and where are the current shortcomings, which generate the best opportunities to increase the efficiency of the Emergency Department under study. The proposed architecture is shown in Figure 2, featuring, at the top, the components of **production** and **management** of Figure 1. Now the **state update and reporting** to management and production is disaggregated into two: the **legacy systems, ERP and others**, which include all traditional type of information systems support, and the **intelligent support** to production and management that includes several variants of analytics that exploit information from traditional systems to provide options that may go from alerts and recommendations to automation of production or management activities. Implemented real cases of this type are:

- In the Emergency Department of a national university hospital, monitoring the flow of each patient, with the available information systems, allows detecting situations of delay, lack of attention, lack of exams and many others that are made known to doctors and nurses so that they execute the corresponding correcting actions. This case corresponds to the **Level I** support defined in Figure 2.

- In the Emergency Department of a national children's hospital, the Triage was automated using a predictive model which, based on the information that is captured for each patient, recommends a category or index for each patient based on his or her severity. In another hospital, predictive models were developed that anticipate congestion in the Emergency Department for the purpose of recommending preventive actions, such as assigning more nurses or adding beds[22]. These cases correspond to the **Level II** analytical support defined in Figure 2.
- Asthmapolis, an organization that gives services to asthmatic patients in the USA[23], was motivated by the fact that around 26 million people suffered from asthma in 2003 in this country. The annual cost of treating this condition was estimated at $50 billion for medical expenditure, plus a further $6 billion in additional indirect costs resulting from missed school and days off work. This considerable expense is to some degree due to the patients themselves, who do not follow their treatment procedures properly or are not in regular contact with their healthcare providers, who then lack feedback on how the treatment is going and under which conditions attacks continue to occur. It has been calculated that if patient treatment could be better monitored, 80% of all asthma-related hospitalization could be avoided, and that the mortality rate from asthma could be reduced by 20%. The technology that Asthmapolis has developed has several objectives, one of them being to help healthcare workers to treat their patients more effectively as a result of monitoring their treatment on an ongoing basis and collecting precise data on the environmental conditions under which patients use their inhalers. When implemented, after three months, 50% of these patients were able to track and manage their asthma condition proactively, while 70% of all participants in the study stepped up their overall self-monitoring activity. This case illustrates **Level III** support of Figure 2.
- A Chilean children's hospital decided to send chronic patients with respiratory problems to their homes to optimize bed utilization. They had a monitoring process designed by the hospital and monitored by children’s relatives, from which need for medical attention was determined. Then we developed a new design based on on-line monitoring of medical variables —such as temperature, cardiac frequency and respiratory frequency— and a diagnosis data-based

[22] Barros (2013)
[23] Barros (2017)

analytical model to determine when the patient is in crisis and needs medical attention. All this is supported by computing and telecommunications technologies that make the process effective. The new process been successfully implemented at the hospital[24]. This case illustrates **Level IV** support of Figure 2.

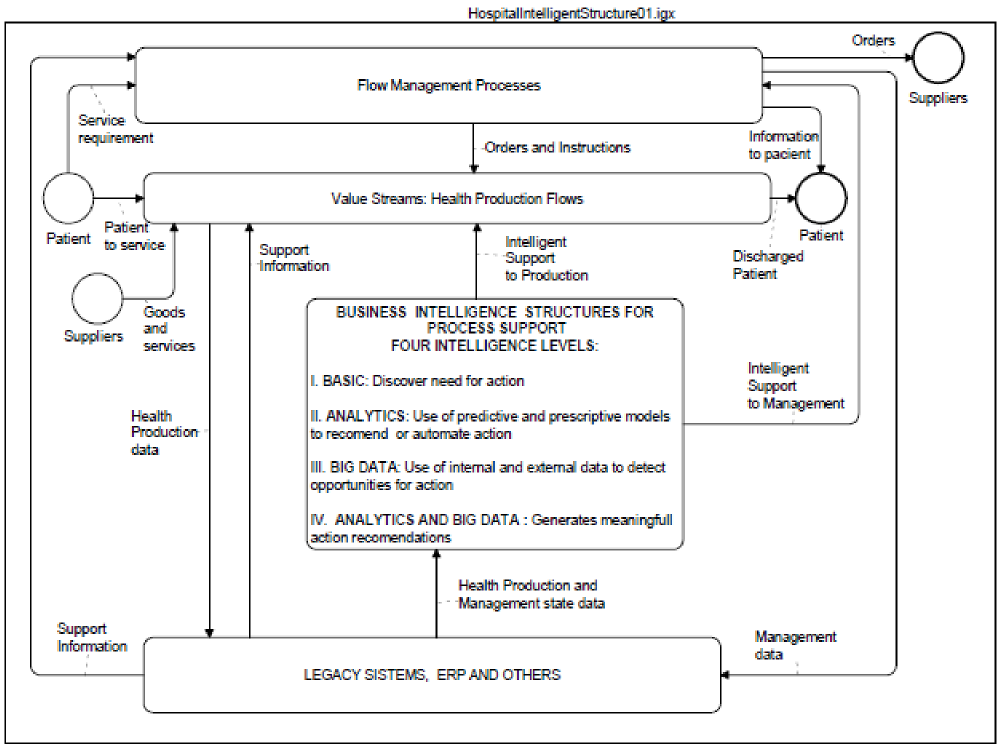

Figure 2: Simple architecture for a hospital

The previous model allows defining three design problems, which are as follows:

i. **Design of the production flow**, which, in turn, requires the design of the medical service provided and the sequence of activities that allow it. First design includes, essentially, medical practices —e.g. assessment, examinations, diagnosis, reassessment, procedures and discharge— and the second, referred to as **case management**, which involves determining step by step, depending on the results, the sequence of actions to be performed on the patient. The complexity of this design is that, in most cases, it cannot be explicitly defined for each type of medical situation faced and must be determined according to each particular case. However, it is possible to order the actions, both on the flow to be followed and the places in which they are performed for different groups of patients, resembling a production line. We will apply this idea

[24] Barros (2017)

in the real case of the production design of the Emergency Department of the public hospital we are presenting, where the situation was chaotic, since all patients shared the same facilities and the same doctors without any follow-up of their status. Another case of flow design, previously summarized, is the treatment of children with chronic respiratory diseases in their homes with computer monitoring, where the difference is that it is a new workflow founded on state of the art technology. The previous two cases obviously mean higher production with the same resources and lower risk of crisis in care due to lack of resources and, also, less risk to the patient. This flow design is present in the medical professional literature and the proposed solutions, independently from ours, go on the same line[25]. Our thinking is that national public hospitals have not such designs and the production flows that occur are the result of good will and intentions of the physicians and other professionals with an evolution by trial and error. Therefore, first and foremost, one should analyze the situation of such flows and submit them to the proposed design, taking into account the frame of reference that we have been developing.

ii. **Design of Management Processes** that manage resources associated with the production, including all that are needed to operate: doctors, nurses, service exams, beds, operation rooms and many others. Depending on the expected levels of demand, the resources must be assigned prior to the different steps within the flow of production. A way that allows good designs to make such assignment is to use support of the analytical Level II of Figure 2, which develop predictive models of demand and optimization or simulation models for resource allocation. We have developed several cases in which we have used this approach in medical resource and infrastructure in emergency, operating rooms between different specialties, outpatient capacity and inpatient beds. There is also a design associated with the programming of resources allocated in the previous point; for example, patients for surgery and outpatient programming, doctors´agenda of outpatient care, operating room scheduling, complex installations of imaging, medical specialists and several others. We have developed cases along this line in the country related to patients waiting for surgery and outpatient programming, on the basis of waiting lists, prioritized by medical factors, medical ambulatory agenda setting and scheduling of use of beds and operating rooms[26]. It is evident that this design depends on the configuration of the

[25] Urgent Matters, Stanford Health Care (2017), Shih & Pierson (2017)
[26] Barros (2017)

production workflows; then one should design first such flows, if it is necessary and feasible, and for the resulting production set up, design resource management processes.

iii. Design of Information Systems

Information systems may contain the following elements:

- "Legacy" systems tailored to the hospital needs by staff or external services, which have typically been built by aggregation of features, using old technology of software development. They are, in general, obsolete and the trend is to replace them by more modern technology, which is listed below.
- ERP type systems, which are standard prebuilt software systems that can be configured for a particular hospital. The most popular of this kind for hospitals are the ones that allow electronic patients records, with a series of add ups that allow to generate reports based on these data. They can be installed on the hospitals computers or reside in the cloud or provider´s facilities. There are a number of other systems of this type for hospitals, allowing to support management of users´ accounts, management of supplies and suppliers, staff payroll and many others.
- Systems that generate and capture data from systems outside the hospital, as it would be the example we gave for patients with asthma or children with respiratory problems; also the data capture of diabetic patients which are collected by some companies and offered to hospitals for the purpose of prevention; data from primary attention centers that were made available to hospitals in order to know in advance features of the demand to be faced coming from those centers; and many others one can imagine, such as use of sensors associated with chronic patients who measure vital signs and transmit them over the networks.

The foregoing constitutes a progression in the improvement of hospitals´ systems that is taking place in the world, which must be the consequence of the advance that is accomplished in the design of medical flows and management. The wrong approach, which all private and public hospitals have followed in Chile, is to develop or buy software systems first, thinking that the mere implementation of these will produce the improvement in medical workflows and management. This has not happened, as shown by the evidence of the precarious results of significant investments in such software in the country. The right thing to do then is first design the health service production and its management and as a consequence determine the systems that are required**.**

iv. Design of Intelligent Support

This design is a complement to the flows and management design and goes hand in hand with this. Indeed, when such flows and management are designed it appears the need of supporting components that facilitate the tasks that are required. For example, the new workflow designed for treatment of children with respiratory problems in their homes requires, in addition to data capture in the same household with appropriate instruments described above, intelligent processing of captured data, with a predictive model, is needed in order to establish the possibility of crisis of the patients and inform the doctor when there is risk. It is clear that something similar could be done with data from diabetic patients captured in clinics or in line, with direct measurement on the patient, captured by the network, allowing prediction of patients´ crisis and preventive action. Another relevant case is emergency in hospitals, where we have shown that, based on data from existing systems of electronic patients records, valuable intelligent support for doctors and nurses can be given as to prevent risk of patients; for example alerting when there are excessive delays or alerting when a patient at high risk have a required exam already available. In terms of management, in operating room scheduling, we have shown that the automatic generation, with intelligent logic, of surgical tables that consider medical priorities and maximize the number of interventions produces improvements on the order of 20% of greater production.

3. Design Approach

Design approach is adapted, from all the ideas above, to the hospital under study, which is a large hospital with a demand for emergency of up to 5000 patients per month, mostly seniors. We focus on the Emergency Department because it is a critical area of the hospital with long delays and periods of crisis that have frequently led to stop attention. The characteristics of the approach are as follows.

Consistent with the architecture of the Figure 1, this hospital has basic systems, one of which captures the information from patients as they progress in their treatment and generates a clinical record. We will use such data to analyze patients´ flow behavior and determine where the best opportunities are for design innovations in the production flow, using the ideas of an intelligent support of the Type I.

Prior to any analysis, we built programs to check for completeness, correctness and consistency of the data. Patients are classified in the data in categories D1 to D5 according to their disease severity, D1 being the most serious. Using such classification, we generated patterns and models that define similar behavior in the patient groups defined by categories. Patterns and models establish that such groups have similar characteristics in terms of the type of pathology, medical resources and others that are used and problems of delays faced by, as detailed below.

3.1. Length of stay (LOS) and use of resources

First, we considered the LOS of patients in the emergency attention boxes. Figure 3 relates, for the last 6 months, the severity of the patient condition (Categoria) with the demand, measured by amount of services (Prestaciones), and the box´s hours. The demand (Q Episodios) is very concentrated in M2 and M3 patients, as well as the amount of services (Q Prestaciones), and, consistently, with the box´s hours (LOS). This justifies focusing on M2 and M3 patients, which concentrates 90% of the resources used. Also, it is concluded that to more severity, more services are demanded and for less severity less box´s hours are needed.

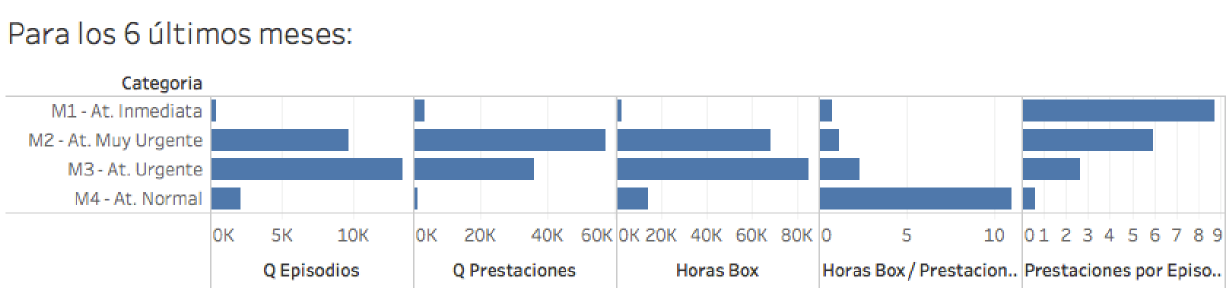

Figure 3: Demand and LOS for patients´ categories

3.2. Value Stream Analysis and Delays

The following analysis identifies the activities that do not add value to the patient flow. Improvement of execution activities may exist, but also improvements in their management can eliminate delays. The idea behind this is to identify the sequence of activities that the patient go through and their associated times to identify improvement opportunities, such as: to eliminate inactive times (team synchronization and coordination), reduce execution times and adjust clinical protocols.

Figure 4 presents the overall attention times, from the patient arrival at the Emergency Department until they are discharged. The data allows the determination of the following times: arrival to categorization, categorization to attention in boxes, and attention to discharge, corresponding to the bars shown in the figure for each patient´s category.

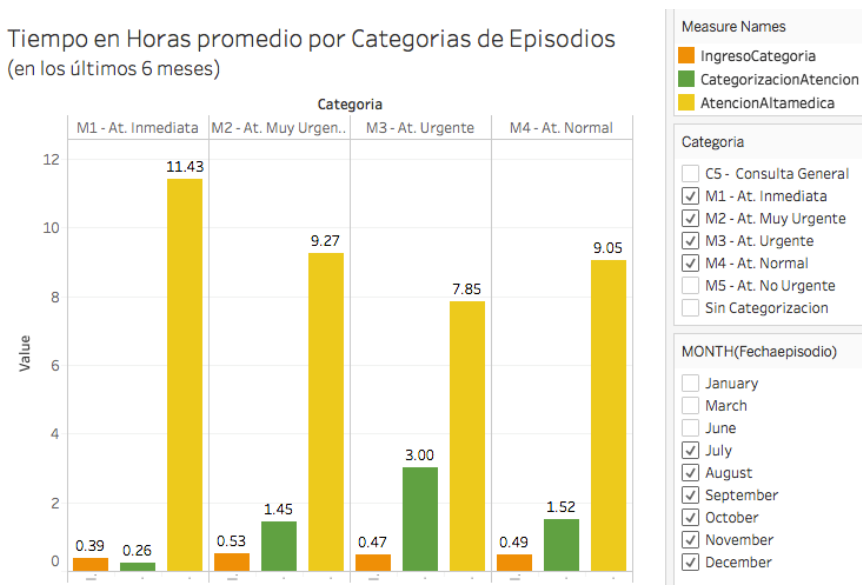

Figure 4: LOS for attention steps

The average times of Figure 4 are directly proportional to the severity of the patient´s condition. Despite concentrating the bulk of patients, category M3 has a box´s mean-time (yellow bar) of 7.85 hours, less that M2 and M1, but the M3 total box´s hours is larger, as shown in Figure 3.

In order to expand the knowledge of the clinical care process and therefore open further clinical stages involved during care, a random sample was generated for one hundred reports of attention data for the month of December 2016. The resulting sample is characterized in the following way: 46% episodes of female patients of average age of 52 years and 51% episodes of male patient of average age of 50 years.

Then, it is possible to know in greater detail the clinical history registered by each episode, in terms of what were the different types of care given to the patient during his stay at the Emergency Department, who was the professional responsible on every stage of the care cycle, when the care happened, when a certain service of support was requested/delivered, and when some event that was accounted as a landmark took place, depending on the type of information that is registered in the report. The previous data makes it possible to generate a first approach to the Value Stream, which is shown in Figure 5.

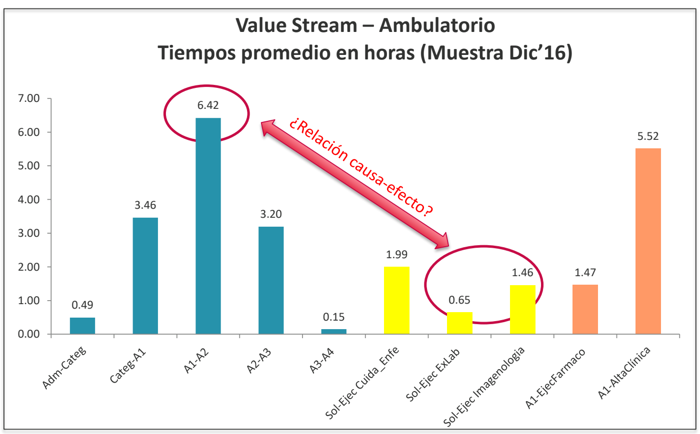

Figure 5: Value Stream Emergency Service

The first five columns represent successive stages:

Adm-Categ: Average time between admission and categorization (triage)

Categ-A1: Average time between triage and first medical attention

A1-A2: Average time between first and second medical attention

A2-A3: Average time between second and third medical attention

A3-A4: Average time between third and fourth medical attention

The next three yellow columns are referred to supporting services that are key to medical attention, characterized by request and execution times in the record.

Sol-EjecCuidaEnfe: Average duration between the request and the execution of nursing care

Sol-EjecExLab: Average duration between the request and the execution of laboratory tests

Sol-EjecImagenologia: Average duration between the request and the execution of imaging tests

The last two average columns represent non-successive temporal extensions:

A1-EjecFarmaco: Average time between first medical attention and administration of prescribed medicine

A1-AltaClinica: Average time between first medical attention and patient discharge

The previous graph shows that the greater average time of 6.42 hours corresponds to the stage between first and the second medical attention. This delay raises the necessity to analyze the potential cause-effect relation between this one and the delay in the execution of examinations, laboratory and imaging.

Therefore, the opportunities oriented to the reduction of the more significant identified delays are mainly:

- Coordination between clinical attentions
- Optimization of practices in support services for clinical attention

This way, in order to achieve coordination and optimization to streamline the attentions, it is clear the need for the design of the production flow of patients M2 and M3, which are the ones using more resources, including the medical practices and support service´s practices.

3.3. Analysis for protocol design

Here we perform a statistical analysis of the diagnosis groups that more frequently appear in emergency´s patients to generate protocols that standardize attention and shorten the hospitalization time before discharge, with, possibly, fewer resources. It is done for a random sample of patients´ records. The following metrics were determined for each of the sampled patients:

- **a.** N ° de episodios
- **b.** Total bed´s days at emergency hospitalization
- **c.** Total bed´s days waiting for exams
- **d.** Bed´s days associated with patients diagnosed with cancer with extended studies
- **e.** Days waiting for indicated inter consultations
- **f.** Bed´s days of patients with therapeutic limitations
- **g.** Waiting days for indicated surgery execution
- **h.** Waiting days for home indicated hospitalizations that fail to realize by difficulties with the families of the patients.

Of the above metrics, all, except “a”, consider bed´s days waiting for some action or decision on the patient and therefore they may have patterns that can affect the hospitalization days and bed use, providing opportunities to reduce them. The results of groupings discovered are summarized in the Table 2.

Etiquetas de fila	Episodios	Suma días cama	Suma de Días cama adicionales por patrón
Cancer en estudio	2	7	5
Ex. Pendiente	5	28	16
IC pendiente	8	53	28
Limitación terapeutica	7	54	34
Sin patrón	22	55	
Requiere cirugía	2	8	8
Retraso H. domiciliaria	1	8	3
(en blanco)			
Total general	47	213	94

Etiquetas de fila	Episodios	Suma días cama	Suma de Días cama adicionales por patrón
Cancer en estudio	4,26%	3,29%	5,32%
Ex. Pendiente	10,64%	13,15%	17,02%
IC pendiente	17,02%	24,88%	29,79%
Limitación terapeutica	14,89%	25,35%	36,17%
Sin patrón	46,81%	25,82%	0,00%
Requiere cirugía	4,26%	3,76%	8,51%
Retraso H. domiciliaria	2,13%	3,76%	3,19%
(en blanco)	0,00%	0,00%	0,00%
Total general	100,00%	100,00%	100,00%

Table 2: Grouping statistics

Groupings that have greater incidence are patients waiting for the execution of examinations and consultations and patients with therapeutic limitations, representing 53,19% of beds´ waiting days, shown in color in the table.

From the sample results it can be inferred that hospitalization times presenting greater opportunities for improvement are the following:

- Waiting times in the conduct and report of examinations, with greater emphasis on studies of cardiac imaging.
- Waiting times for assessment of inter consultation specialists
- Times associated with discharges (due to transfers, discharges and others)
- Need for protocols that support the doctor to speed up the diagnostic confirmation
- Time to get a bed in required medical services.

The design will focus on patients M1-M2 to reduce stay and on the M3 to reduce waiting times. Regarding the most relevant diagnoses, there are 3 diagnostic groups taking 74% of bed´s days in the emergency; this data considers patients who have DG ICD 10, with a total of 4091 bed´s days of 690 patients over a period of 5 months, as shown in Figure 6. So the protocols will be for Neurology, Cardiology and Bronchopulmonary.

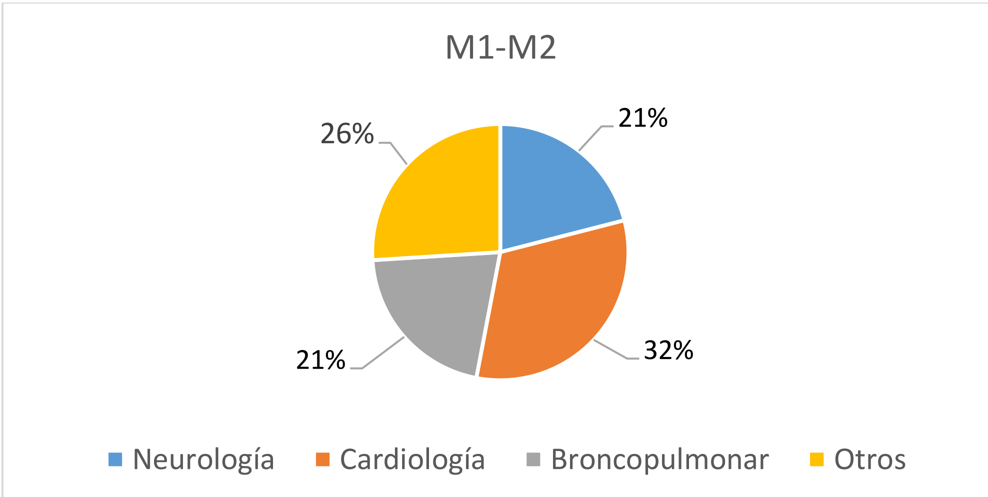

Figure 6: Frequency of Diagnosis Groups

4. Emergency Design

For the Emergency Department of the hospital analyzed in the previous section we did and implemented a design prioritized according such analysis, which is summarized it below.

4.1. Structure and Flow Design

We have already determined, in Section 3.1, that patients classified as M2 and M3 during triage represent more than 90% of resource utilization. Therefore, the design is concentrated in these patients, since, in addition, they are priority because of severity. These patients were not differentiated and competed for the same resources with all the other patients in current situation. In order to improve patient flow, which was mixed and confused with the rest of the patients, segregated production lines were defined for the M2 and M3; also, for such lines to be logical and orderly, the physical space was remodeled with an architectural project.

The pre-design flows in the previous physical structure were as in Figure 7.

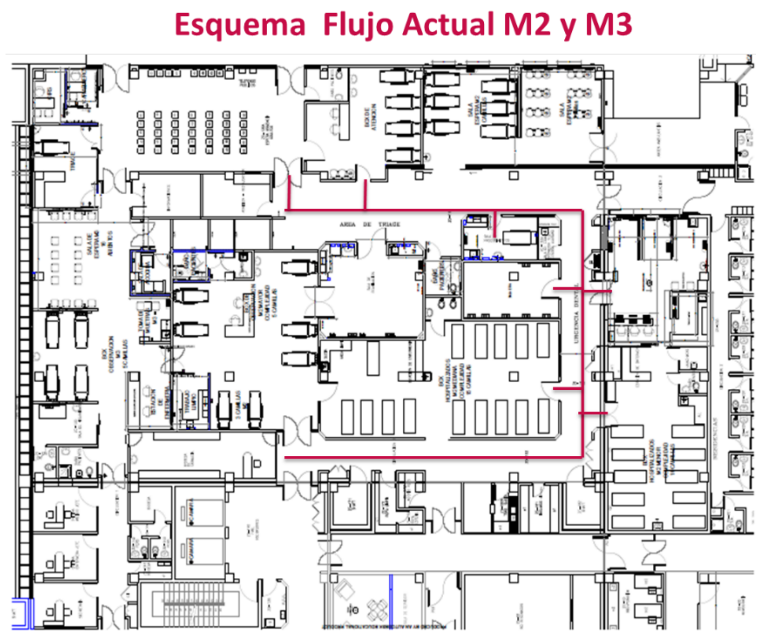

Figure 7: Current physical structure and flows

Due to the previous analysis and after an exhaustive in-situ observation, we were able to detect the following problems in the flow that made it less efficient:

- Triage Infrastructure mixed the nurse evaluation with medical care, and the flow of medical care was not well defined.
- Attention room locking, due to exams waiting to confirm diagnosis, results in attention stagnation.
- The reevaluation of the patients generates that the waiting room moves to the interior of the Emergency Department, increasing waiting times and patient's dissatisfaction.
- Merging of M2 and M3 patients occur during the reevaluation process.
- Traceability of patients in the interior of the Emergency Department was a constant unresolved issue.

Given all of the above, it was determined that the following designs would help solve the identified problems and obtain a better structure for the flow of patient care:

- Separation of medical and surgical flows for patients categorized as M2 and M3.
- Exclusive areas for patients M2 and M3: Waiting room, Treatment Room, Hospitalization Box.

The proposed design can be seen in Figures 8 and 9, which shows in detail the physical restructuring and redistribution of flows, both for M2 and M3 categories, in versions discussed and approved by the hospital's professionals.

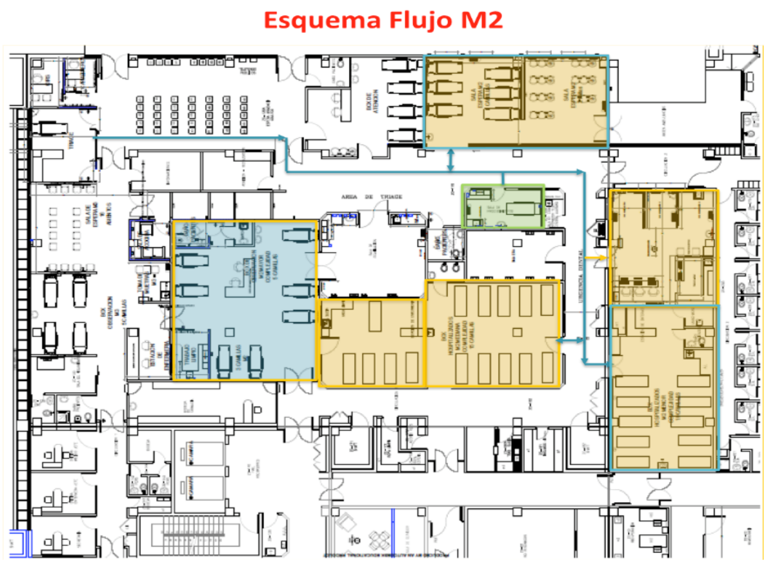

Figure 8: Configuration and flows for M2 patients

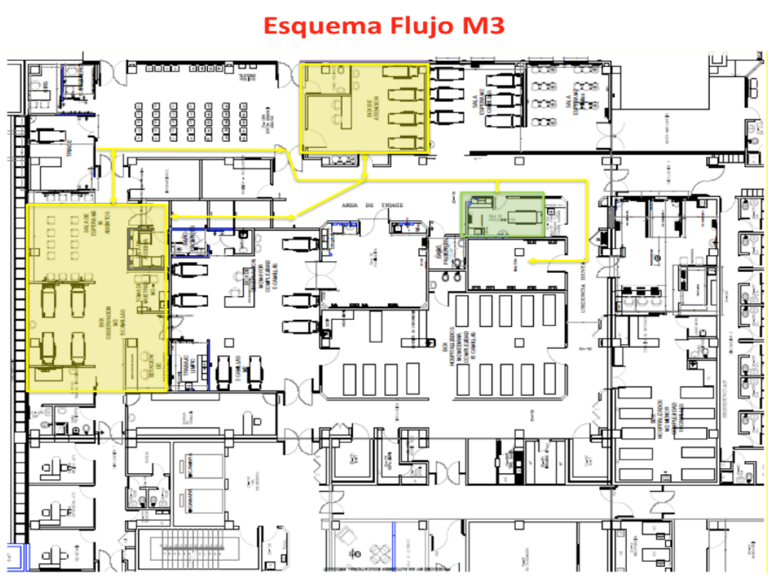

Figure 9: Configuration and flows for M3 patients

The flows can also be represented more precisely by means of BPMN diagrams, which are shown in Figure 10. This means a very well-defined flow in which patients go through places identified by signaling where well-specified medical actions are performed from where they go to the next step under well-established criteria. This produces an order in which patients are identified and, therefore, their situation is known at all times. This makes a huge difference in terms of physical ordering, elimination of delays due to "loss" of patients, assurance that more severe patients are perfectly identified and are not at risk for late care, better and more effective use of doctors' time and nurses and better coordination with medical services (i.e.: clinical laboratory, imaging, among others).

In addition, the theory justifies such design, by concentrating a group of professionals in a less varied set of activities, which favors specialization, reducing the complexity of coordination, increasing productivity, as discussed in the coordination theory of Section 2.2. In addition Agency Theory, summarized in the same section, justifies this design, since we are decentralizing the production execution decisions in the group that runs it, without direct intervention of the hierarchical levels in the management of the flow, but with a set of workflow rules and protocols that ensure good performance; if such rules are approved by the hospital authorities, due to correct interpretation of the interests of the principal, we have, at the same time, low residual, information and opportunity costs. On the other hand, within international practice, a hospital as important as Stanford University's has decided to implement segregated lines, Split Flows, as a means to accelerate flow and increase productivity[27].

The new flows were implemented during June and July 2017. Comparing patient's waiting time during these periods and following ones, the results in Figure 11 show the evolution of LOS for different steps of the flow, yellow bar being total LOS, along the observed months. Total LOS clearly shows a systematic decrease starting July, which can only be explained by the new design, since demand for emergency has had normal figures for the surge winter period in Chile. The continuous decrease can only be explained by a learning effect about the new flows and up to August, last month with complete data, there is about a 20% total LOS reduction, with a continuing decreasing tendency. Another comparison was made between 2016 versus 2017 winter surge period (Figures 12 and 13), where the decrease is of almost 50% for July and August with similar demand and resources.

[27] Urgent Matters (2017)

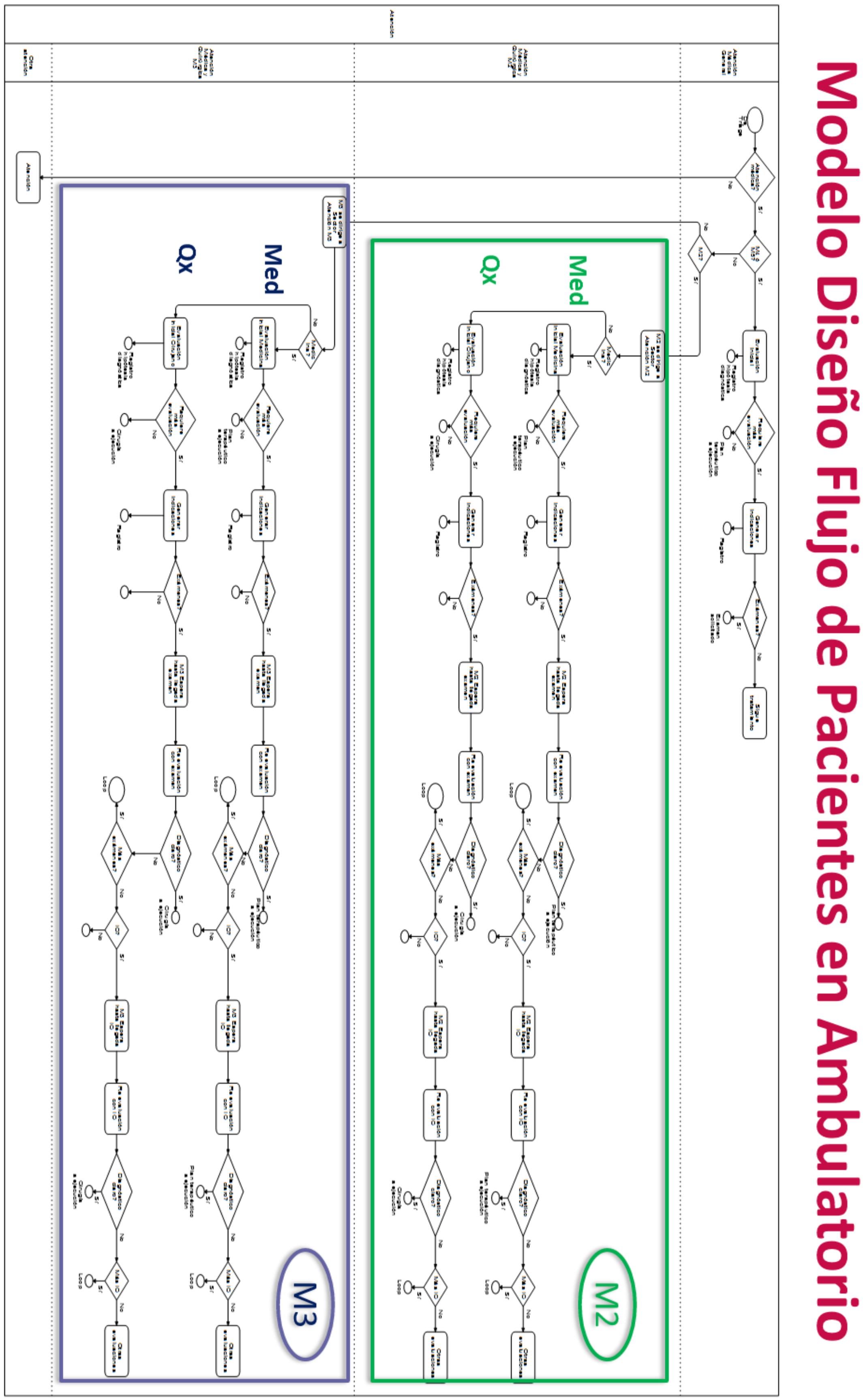

Figure 10: BPMN for new flows

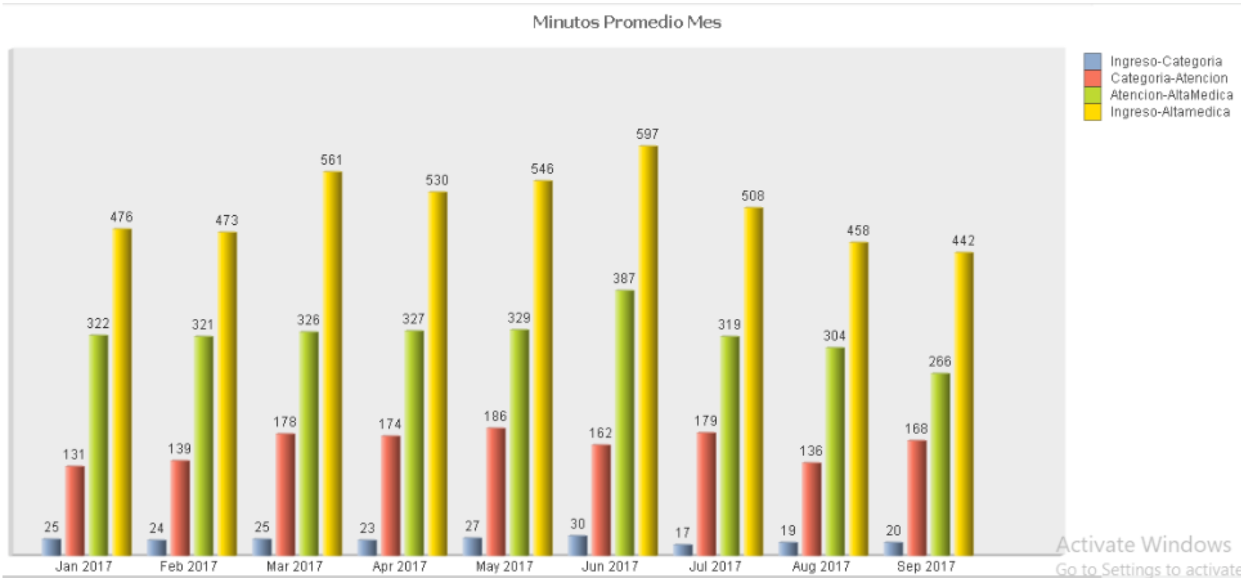

Figure 11: LOS monthly evolution

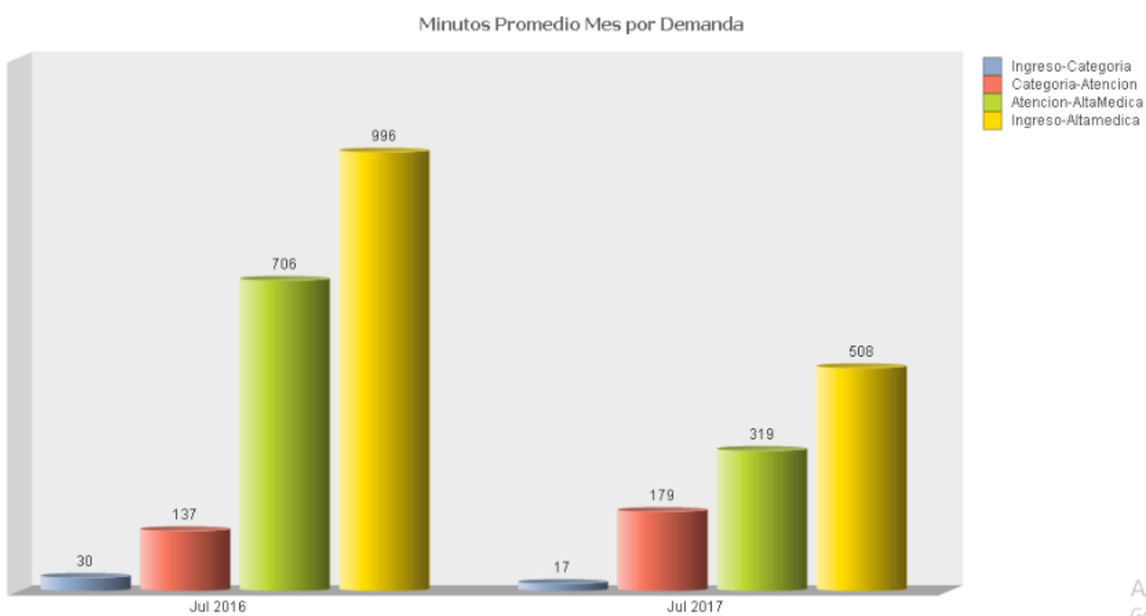

Figure 12: LOS comparison July 2016 – July 2017

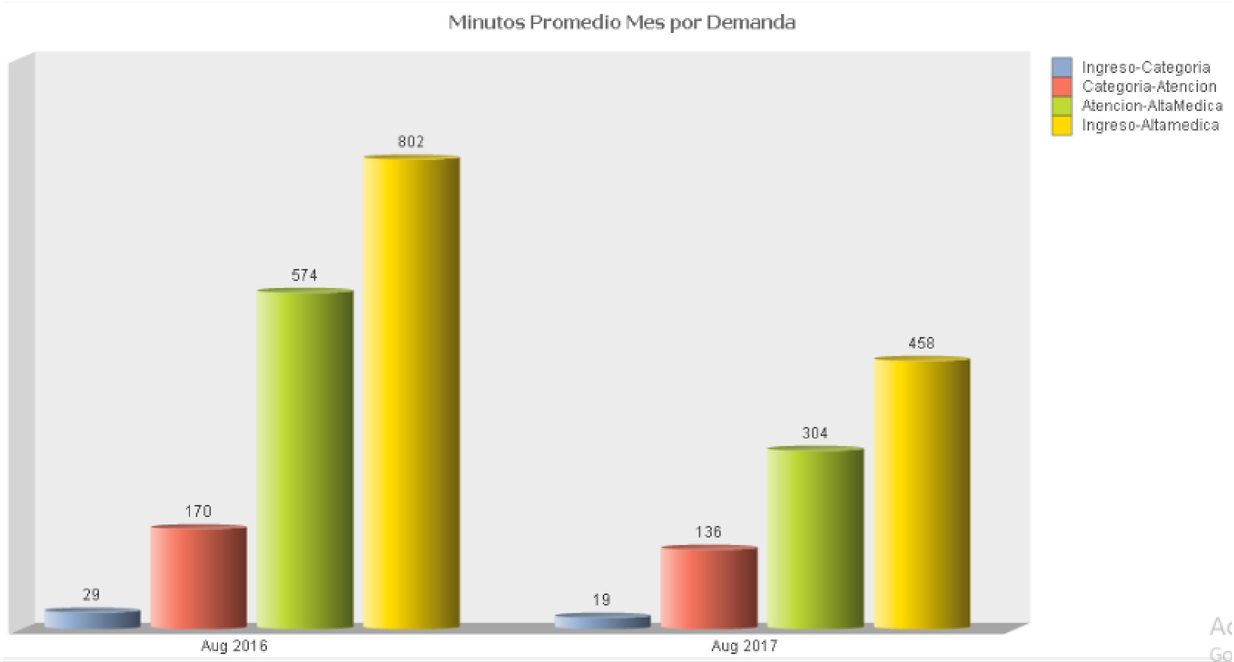

Figure 13: LOS comparison August 2016 – August 2017

The presented results, which are very significant, can be explained by:

- Current infrastructure allows to clearly differentiate the route of M2 and M3 patients from the moment they are categorized.
- Patient identification and placement was improved due to the use of colored bracelets and differentiated areas for each category. The problem of traceability of patients within the Emergency Department is solved.
- M2 and M3 flows have their own, dedicated medical and nurse staff, solving the problem of access blocking for each category.
- Medical attention stagnation has been minimized and consultation room blocking is becoming less common, reducing waiting consultation time.
- Specialty consultation is conducted for each category of patients in their respective consultation room
- Patient reevaluation (second or confirmatory consultation) is facilitated since they have specific differentiated areas: waiting room M2 and M3 patients, different from the general waiting room, which facilitates the patient's location, avoiding the fusion of patients that occurred previously.

- Differentiated areas allow for treatment (e.g. drug administration) to be conducted in the designated waiting room (M2 or M3), minimizing patient´s waiting time for intervention and freeing beds in consultation rooms.
- M2 and M3 patients have their own, separated nursing stations allowing for minimizing time of blood sample extraction and other procedures, as well as reducing time to laboratory and resulting waiting time.
- A maximum waiting time for lab results was established (2 hours) as well as a rule for the delivery and reception of lab results, which is detailed later.

We are currently working on a finer analysis of time used in different flow activities by the professional´s teams involved in emergency´s shifts, to establish whether there is an efficient use of time and resources and, possibly, identify opportunities for better use.

Modularity and case management are also present in the flows, since they use common service modules for examinations, laboratory and imaging, that are managed with well-defined rules we will present in following sections. Also patients´ flow is defined by the lines, but there are decisions about the patient that need a case management capability, for example first diagnosis, which will eventually be provided by intelligent support of type II of Figure 2.

4.2. Design of Medical Protocols[28]

In Figure 6, it is shown that more frequent pathologies in emergency, for patient that need to be locally hospitalized in order to have a diagnosis confirmation, are Cardiology, Neurology and Bronchopulmonary, for which protocols are developed.

The protocols emphasize medical workflows that allow to solve the problems that arise in the gray areas of clinical decision making and are consistent with the flows´ design from the previous section; also they define responsibility milestones and measurable time variables for each stage of the flow. The fundamental ideas of the construction of the protocols consider the following elements:

- Identification of critical nodes within each workflow.

[28] What follows in this section is a compact review of a much more complete work done by MD I. Paredes, a member of this project´s team.

- Identification of the health care stage with greater impact to shorten attention times, which is the diagnosis confirmation.
- Identify binding variables within the protocol and relevant biomedical data in the workflow.

Protocols have a general logic that is specialized to particular pathologies. It takes the form of a flow diagram where the following steps are included, which are exemplified with the Cardiology protocol:

i. **Identification of background variables**, such as demographic data, derivation origin, physical location, morbid history, patient drugs use, reason of Cardiology entry and hypothesis of entrance diagnosis.
ii. **Identification of tests for the general practitioner**, such as ECG, Rx Thorax Ap-Lat, Hemogram, and ELP. These diagnostic tests should be requested by general practitioner before evaluation by the cardiologist.
iii. **Identification of tests for specialist,** such as echo cardiogram (requested by cardiologist) and Angio CT.
iv. **Identification of treatment variables,** such as Aspirin, Clopidogrel, Heparina, Estatinas, vasoactive drugs, noninvasive ventilation and CVC for Cardiology patients.
v. **Criteria for discharge to home**, such as normal ECG, Troponin in 2 takes normal with values less than 14 and echo cardiogram normal.
vi. **Post discharge actions for emergency cardiac patients,** such as control in Cardiology of an outpatient county facility within 3 days of discharge from emergency, cardiological recipe for 15 days and diagnosis of cardiac discharge with ICD 10 coding.

To illustrate the above ideas we show the design of the Protocol of Cardiology. The protocols take the form of a flow diagram as shown in Figure 14. This is complemented with the logic for the specialist inter consultation activity shown in Figure 15. This a key part of the flow, since a prompt and well defined specialist intervention assures a correct and timely diagnosis confirmation. This is complemented in the next section with the design of the process that manages the coordination between inter consultation requests and the specialists that provide the service, which is a shared with other hospital workflows, such as inpatient care.

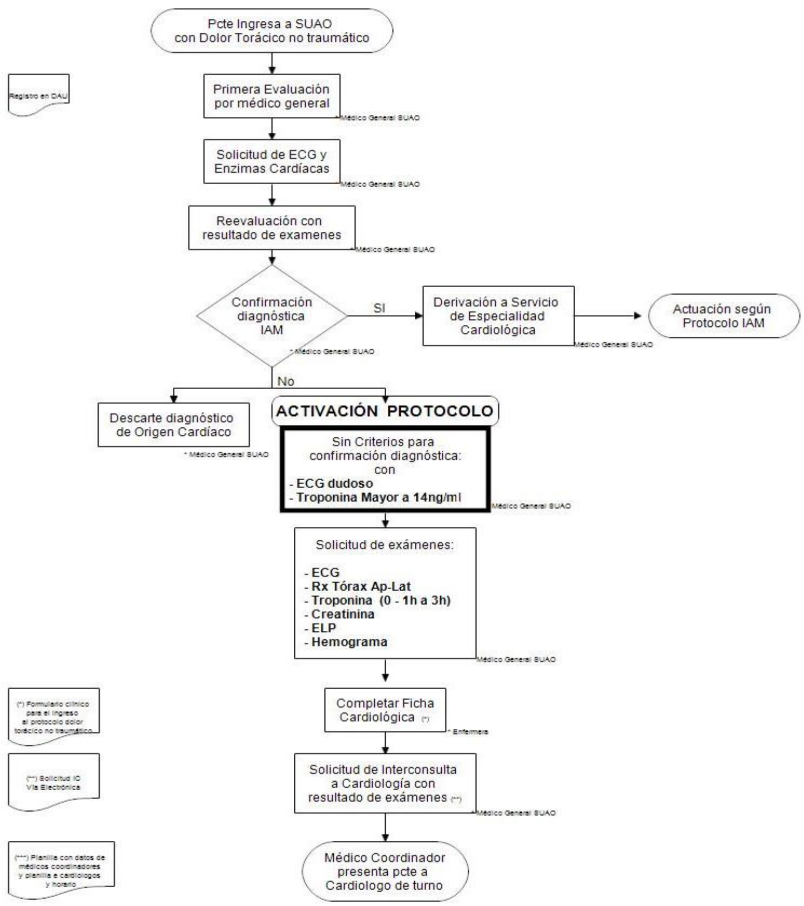

Figure 14: Flow diagram for Cardiology Protocol

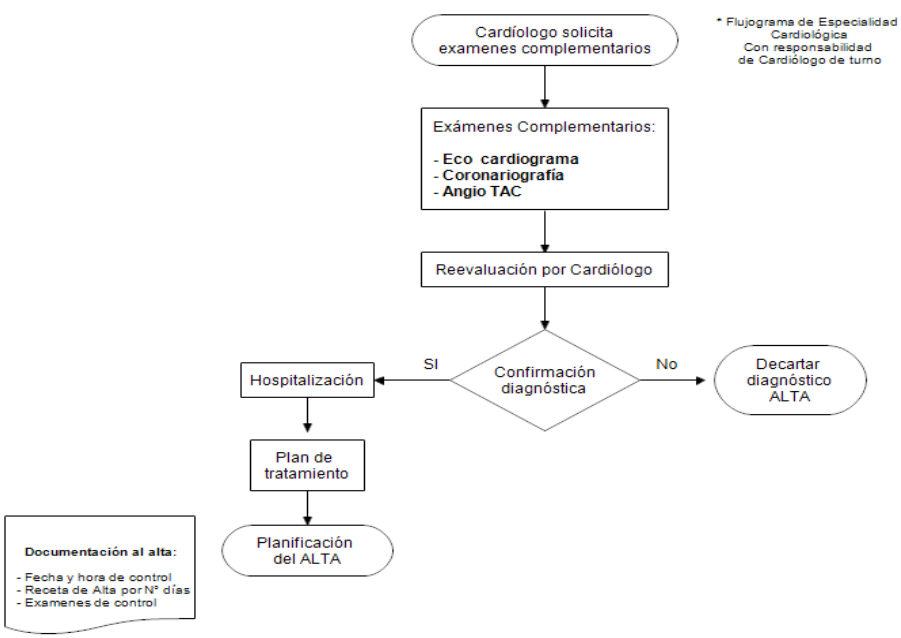

Figure 15: Flow diagram for Cardiology Inter Consulting

The implementation of this protocol has increased almost 4 times the number of patients´ resolutions that occur on the same entry day, as Figure 16 shows. Also there has been a decrease of the average bed´s days used by the patients from 6.2 to 1.3. This obviously reduces the risk of the patient and increase the efficiency of resource use.

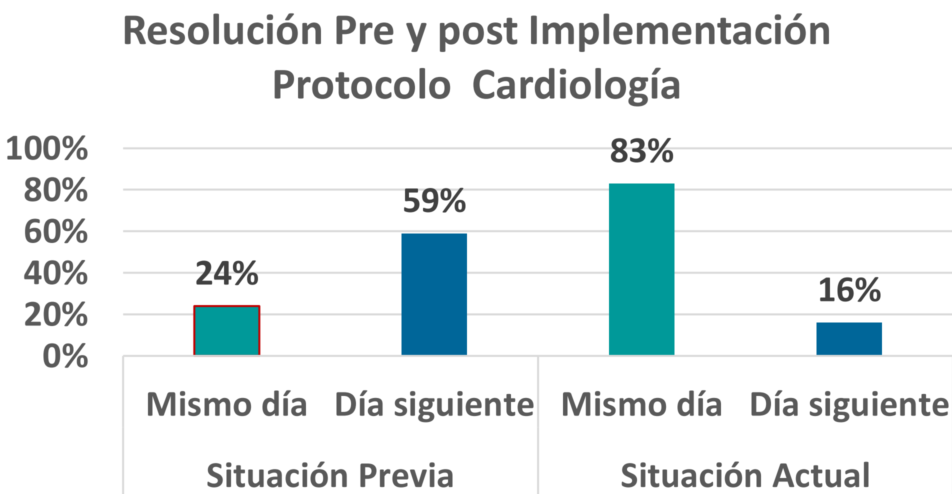

Figure 16: Cardiology resolutions first and second day after entry; current and improved situations

We are currently working on the other selected protocols. Also further use of protocols to formalize the first patient evaluations in the flow presented in previous section is being considered. Final objective is to continuously improve the logic that formalize medical knowledge in order to improve diagnosis resolution and correct treatments along the flow, including the possibility of using Machine Learning to generate logic from historical data. This will allow to move to intelligent support of the Type II of Figure 2 by automating the logic to provide on-line advice to medical professionals, as the patient progresses along the flow. Also case management will be possible, since the support will also include the advice on the actions that follow after a certain step of the flow and state of the patient. This is justified by coordination theory due that flow specialization makes feasible logic determination due to less variety in each flow, and also by Agency Theory, since a logic that assures good results interprets principal´s interest and reduce aligning, information and opportunity costs to comply with principal expectations.

4.3. Complementary Designs: Consultations and Examinations

Here, we consider other designs corresponding to services that support the patient flow; main ones are Inter Consulting, for which a protocol was proposed in previous section, and Examination services, which are presented below.

i. <u>Design of practices associated with the request and implementation of consultations</u>

The analysis of information on patients´ stays in hospital emergency, shown in Table 2, shows that the number of days that patients stayed waiting for the execution of the consultations, requested by the treating physicians to different medical specialties, present an opportunity for LOS reduction and better use of resources; this opportunity was exploited with good results in the previous section with medical protocols. Here we consider improving the management of the requests and execution.

A new design was proposed including improvements in three main areas:

- **Formalizing the role of an Inter Consultations (IC) Manager** with responsibilities and authority to manage request and handling of IC.
- **Defining capabilities of attention of various IC medical specialties for the emergency service.** This means defining service agreements with the medical specialties that must be managed and controlled.
- **Improve practices of request and processing of the IC to medical specialties,** including reporting its progress, through the implementation of an information system that supports the process, and improving information flows and control of the process.

Figure 17 shows the new design represented in a BPMN model.

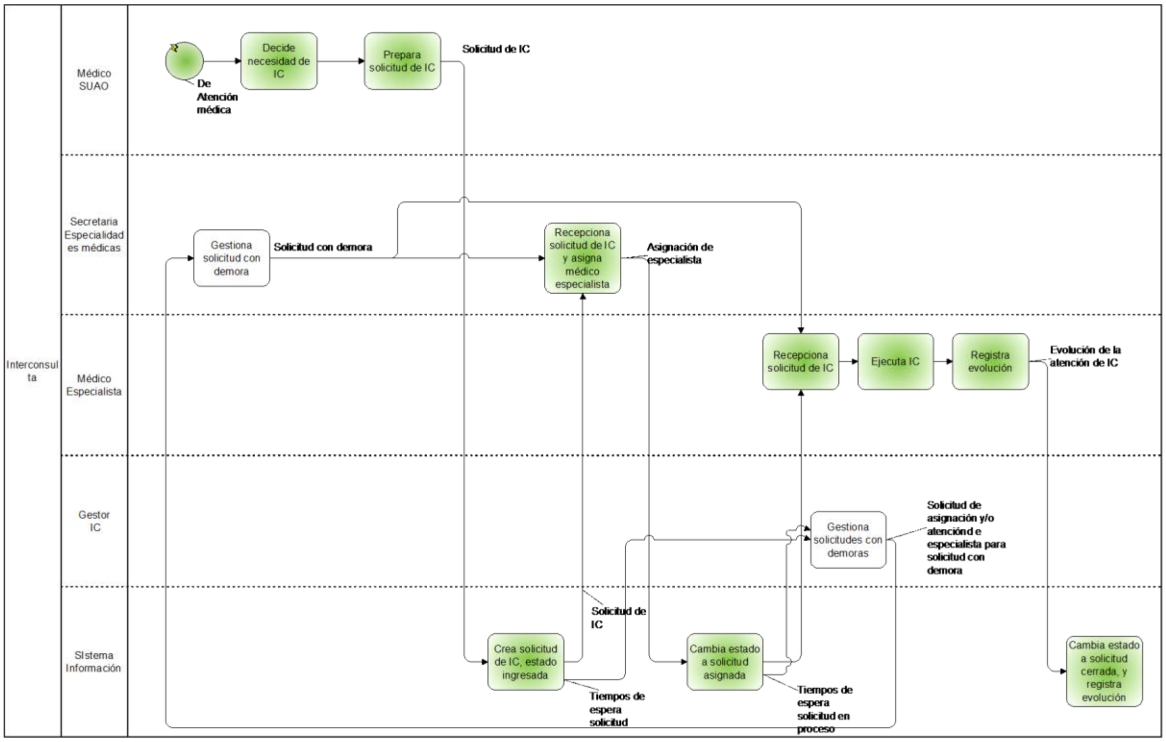

Figure 17: BPMN model for IC management and control

The results obtained with the implementation of this design for Cardiology, as a complement of the protocol of last section, resulted in an increase in the resolution of the consultations by 89% during the same day, which impacts on the patients stay, due to their faster discharge. This allows the reduction of cardiologic patients´ bed days. A key aspect of the improvement is the use of collaboration software, to implement the information system, to coordinate the request and the execution of consultations. Given the good results it is being extended to all specialties. This is an example of incorporation of IT support to the implementation of an intelligence of the type I of Figure 2. IC is also an example of Modularization, since each specialty service, with well-defined practices, is common and shared by several patient lines. This generates a coordination problem that is explicitly solved for emergency, which it is possible to extend to other production lines. The solution is justified by coordination theory that support services specialization and sharing with appropriate coordination mechanisms.

ii. Examinations Service Design

Another relevant item identified within the opportunities to improve and streamline the flow of attention of emergency is the request, processing and reception of laboratory and radiology examinations. In was found that, in both cases, the total times between the request for examination and the use of its results by the treating physician are excessive, with an inefficient use of resources, and that there is potential for improvement. On the other side, and as a result of analysis in detail in the process, shown in Figure 5, it was found that average times for the availability of examinations is high and affects the time for the first diagnosis, which is the largest time in such figure. Hence the following opportunities for improvement are established:

a. **Laboratory examinations**:

The processes that originate the delays are the examination request and the use of its results for medical diagnosis and reevaluation, and their possible improvements are:

- **Request Subprocess:**
    - ➢ Ensure that the medical order follows a single predefined route.
    - ➢ Specialized nurses for M2 y M3 patients.
    - ➢ Improve and standardize sample wrap.
    - ➢ Have separate pneumatic sample sending devises for M2 and M3.

- **Reception Subprocess:**
    - ➢ Results of critical examinations delivered by system.
    - ➢ Nurse should perform regular monitoring of the state of patients with tests requested and update the status in the system.
    - ➢ Alert for nurse and doctor in the system in use when examinations are available.

b. **Radiology Examinations**:

Processes have been detected causing delays; they are the request and the use of examination for medical diagnosis and reevaluation, which possible improvements are shown below:

- **Request Subprocess:**
    - ➢ Ensure the integration of system in use and imaging software.
    - ➢ Specialized nurses for M2 y M3 patients, in order to ensure coordination of the taking of the examination on time and ensure that the patient is properly prepared.

- ➢ Auxiliary service for carrying the group of patients that needs to take the examination.

- **Reception Suprocess:**
  - ➢ Critical examination results through alerts in system in use.
  - ➢ Nurse must regularly monitors states of patients with requested examinations and update the status in the System.
  - ➢ Alerts for nurse and doctor through system in use when examination is available.

Product of the analysis of these situations and incorporating opportunities for improvement found in both cases, the most significant design changes are:

- Using collaboration software to transmit critical values to Coordinator physician.
- Separate pneumatic sample sending devises for M2 and M3 flows.
- Use of microphone to call for patients for sample taking.
- For the processing of samples an internal commitment was implemented in which laboratory - emergency established a maximum period of 2 hours for the delivery of results.

The results obtained to date are that the commitments of the deadlines pledged by laboratory since its implementation to date have a 98% compliance. In addition, Figure 18 shows statistics of average time of availability of the examinations for reevaluation, before and after implementation of M2 and M3 flows with the changes proposed. The decrease is 30% for patients M2 and 80% for the M3, which reinforces the effect of structural changes which the new design flow produces.

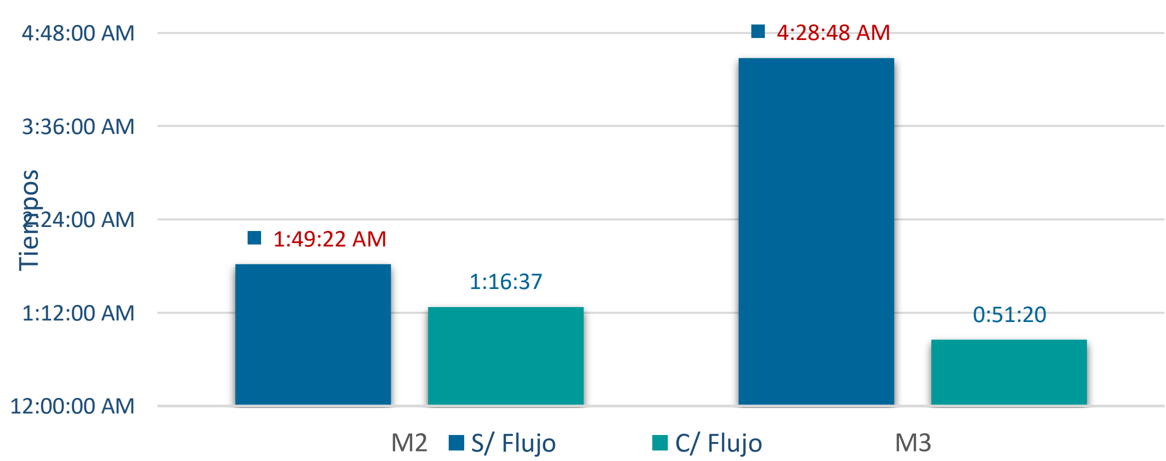

Figure 18: Average times for examination availability pre and post implementation of design.

5. Conclusions and Extensions

We have formally designed and implemented working solutions for the production flow of the emergency of a large hospital with results that improve historical performance, measured by patients LOS decrease, by more than 20%, during the period analyzed, and up to 50%, as compared with the same last year´s period. Obviously this means that a great value has been generated in terms of better service and good use of resources that increase capacity. From this we conclude the plausibility of the idea we proposed that the most important problem of design, in terms of potential improvements, is production design. Also, since most public hospitals in Chile operates in a similar way to the one in which we performed the design, there is an opportunity to extend the solution, using the same ideas, to selected hospitals and generate similar value for them. There is also the possibility of extending the design approach to other hospital workflows, such ambulatory and inpatient, for which similar or greater potential value generation exits. And this posit the question: why continue investing large amounts of resources in news public hospitals, as opposed to the possibility we have proved feasible of generating large amounts of capacity by performance improvements, with much smaller cost?

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