Patient Flow Optimization Using Knowledge Supernetworks and Lean Six Sigma

Chiara Cirrone, Eleonora Di Pietro, Aurelio La Corte, and Alfina A. Torrisi
Department of Electrical, Electronics and Computer Engineering
Email: {chiara.cirrone, eleonora.dipietro, aurelio.lacorte, alfina.torrisi}@dieei.unict.it

***Abstract*—Analysis of hospital processes is essential for development of methods, policies and decision tools for overall performance improvement of an hospital system. Modeling, analysis and management of patient flows, in this context, plays a fundamental role as it may help healthcare managers take decisions and make necessary changes in the process of care. In this paper, it will be shown how supernetwork framework can be effectively used to model and optimize patient flows in hospital systems. A structured problem solving approach based on Lean Six Sigma methodology and supernetwork framework will be used to describe the optimization problem, analyze research outcomes, identify common issues affecting the patient flow and evaluate possible corrective actions. The strength of the proposed approach will be demonstrated by a case study, where it has been successfully applied to the improvement of the patient flow in the context of an Emergency Department.**

***Index Terms*—knowledge supernetwork, lean six sigma, patient flow optimization**

I. Introduction

Recent years have witnessed a growing interest in development of methods, policies and decision tools for improving performances in healthcare management.

People realized that, in order to improve patient outcomes, it is needed to plan and allocate healthcare resources so as to make sure patients could receive the right care at the right time. It could allow to reduce delays in health services and increase quality of care patients receive. An optimal allocation of healthcare resources also would avoid increasing of care costs, while maximizing patient outcomes.

In this context, physicians and researchers have been increasingly paying attention to the modeling, analysis and management of patient flows through the various hospital production units (such as the emergency department, operating rooms, hospital beds or out patient clinics), with the primary aim being to identify methodologies for maximizing hospital efficiency and allowing optimal utilization of resources that better matches to demand [1], [2].

Appropriate modeling, analysis and management of patient flows, in this context, may help healthcare managers take decisions related to capacity planning, resource allocation and scheduling, and make necessary changes in the process of care.

In this paper, an approach pertaining to modeling of patient flows in hospital systems based on knowledge supernetworks will be proposed.

The supernetwork framework allows decision makers to formalize available alternatives, to model their individual behavior in terms of variable criteria and, then, to compute different flows so as to identify optimal capacity of the network [3].

Flows may consist of product shipments, travelers between origins and destinations, financial flows, resource and energy flows, as well as information flows. In the context of a Hospital Information System, flows represent patients moving from one resource and/or production unit to another in the hospital.

The solution of the model allows to calculate the time needed for the complete patient flow through the various hospital production units from the patient's arrival at the hospital to their discharge and first follow-up, and to identify optimal criteria that may minimize it.

A problem solving methodology based on Lean Six Sigma [4] will be used to describe the optimization problem, analyze research outcomes, identify common issues affecting patient flow within a Hospital Information System and evaluate possible corrective actions which could improve patient flow quality.

The paper is organized as follows. In Section 2, an overview of supernetworks is given, highlighting some of their major achievements in terms of theory, methodology, and applications in modern economies and societies. Section 3 introduces Lean Six Sigma methodology and proposes a modified approach which uses supernetwork framework for the improvement of the patient flow quality. Then, Section 4 presents a case study where the proposed approach has been successfully applied to the improvement of an Emergency Department. In the end, Section 5 reports achieved outcomes and introduces future works.

II. Supernetwork and Knowledge Supernetwork

Network is a very long standing and simple concept, but always up-to-date and innovative, that can be efficiently used to represent modern economies and societies.

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Through modeling, analysis, and solution of complex networks, it is possible to model and analyze different aspects of our lives, both in terms of underlying connectivity and functionalities, and to help people to take decisions most convenient for them.

Network models and tools are widely used in different areas of interest, such as transports and traffic analysis [5], logistics and supply chains [6], financial networks [7], and even energy/power management and control [8].

Recently, network models have been further developed to create what we term “Supernetworks”.

Supernetworks are "networks of networks", that allows researchers to graphically represent the alternatives available to decision-makers by means of multilayer-graphs, and provides a method for mathematical computation of the problem aiming at the improvement and optimization of the whole system.

Supernetwork framework mainly consists of two distinct phases: the problem definition and the problem analysis.

First, the problem is identified and a graphical depiction of it is provided. Supernetwork models are represented through a multilayers graph, consisting of different nodes (generally corresponding to decision makers), links (representing connection between nodes) and flows (corresponding to good or data moving through a link, to be transferred to the destination node). Flows generally identify criteria to be optimized, that can be total cost, risk, and time.

Then, starting from the visual representation of the problem, it is needed to assign a cost function to each link. Using a link incurs some specific costs as well as specific risk and time. The decision-makers can weight their individual criteria and optimize their behavior accordingly. The function resulting from the combination of all links' functions represents the scope of the problem. By optimizing this function, we are able to identify the problem optimal solution, that is flows that optimize (i.e. minimize or maximize depending on the objectives), services offered by decision-makers thus allowing the improvement of the whole system.

As shown in Fig. 1, supernetworks can be efficiently used in different applications; see, for example [9], [10] and [11].

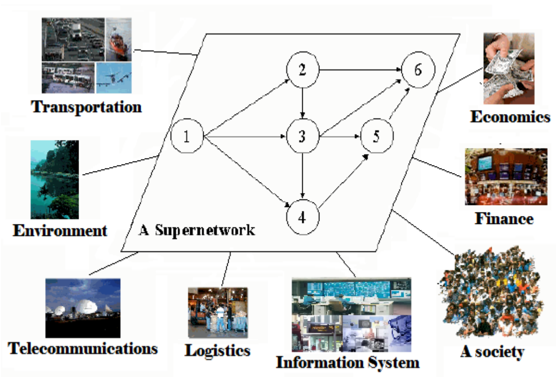

Figure 1. Areas of application of supernetworks

Recently, researchers have shown growing interest in “Knowledge Supernetwork”, a different typology of supernetwork where transaction happening on links regards information data and not physical goods. Such networks can be used to model all problems where knowledge is fundamental and its diffusion must be managed somehow.

There are a lot of challenges knowledge intensive organizations have to face in order to optimize the knowledge production process. The application of knowledge supernetwork allows decision makers to best manage resource allocation processes and satisfy the needs of their ultimate consumers in a fast and efficient way, in an environment where uncertainty and risk is increasing more and more.

A Knowledge Supernetwork generally consists of multiple supernetworks, each one modeling a specific process within the solution, and representing, as a whole, a complex system and the interaction inside it. The improvement of each supernetwork entails the improvement of the whole system.

The knowledge supernetworks have already been efficiently used to optimize news organizations and intelligence agencies [12], [13]. For its characteristics, knowledge supernetworks can also be applied in the context of healthcare, where they can be used to optimize patient flows within a Hospital Information System (HIS).

Clearly, a HIS is a knowledge organization which is involved in knowledge production and dissemination. Besides, it must respond in a timely manner and deals with multiple objectives including cost minimization, time minimization as well as risk minimization. Also, the product is no longer a physical one but rather is in the form of processed information or knowledge.

In this paper, we will show how Knowledge supernetwork can be applied to the modeling and the analysis of the patient flow in the context of an Hospital Information System and will propose a structured approach for patient flow improvement which uses Supernetwork framework.

III. Approach for Patient Flow Optimization

As shown in Section II, Supernetwork framework may help, in the context of healthcare, to model and to optimize patient flows within a Hospital Information System.

Nevertheless, Supernetwork framework does not provide a complete strategy for problem analysis and solving.

In order to correctly solve a problem and achieve quality optimization objectives, it is important to follow a series of steps. Many researchers refer to this as the problem-solving cycle, which includes developing strategies and organizing knowledge.

A structured approach is needed, together with a business improvement model which takes into account all relevant stakeholders, including patients, physicians, nurses.

In the context of healthcare, the most adequate business improvement methodology is the “Lean Six Sigma” [14], [15], [16], [17].

Lean is an integrated system of principles, practices, tools, and techniques focused on reducing wastes, synchronizing work flows, and managing variability in production flows. Lean approach aims at limiting continuous and increasing wastes, by identifying non-value-activities which do not contribute to the quality of product or service and optimizing logical flows so as to find out and remove bottlenecks.

On the other hand, Six Sigma approach uses mathematic techniques to understand, measure, and reduce process variation, aiming at optimizing and controlling processes having real added value. Six Sigma helps to quantify problems, facilitates evidence-based decisions, helps to understand and reduce variation, and identifies root causes of variation to find sustainable solutions.

Lean Six Sigma combines the powerful tools for statistical analysis, typical of Six Sigma, with Lean principles and tools, useful for reducing wastes and delays.

To better control and improve processes quality, Lean Six Sigma uses the DMAIC cycle, consisting of 5 distinct implementation steps, shown in Fig. 2: Define, measure, analyze, improve e control.

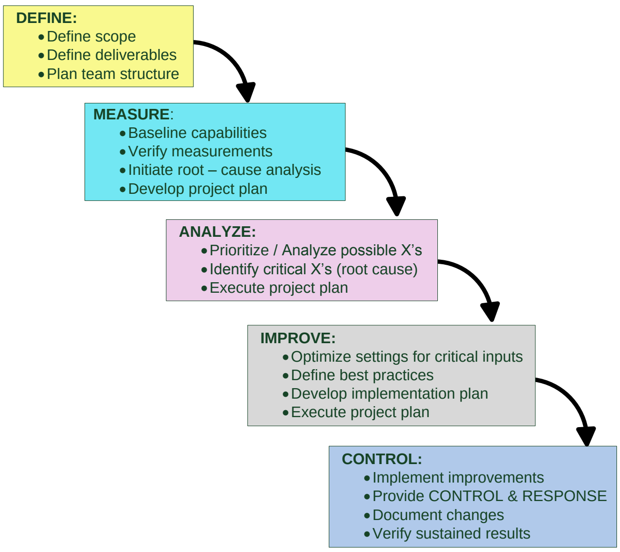

Figure 2. DMAIC implementation cycle

DMAIC provides data-driven practices and tools for improving, optimizing and stabilizing business processes and designs. Hence it can support Supernetwork framework both in the problem definition phase (where DMAIC can help in identifying causes mainly affecting patient flow) and problem analysis phase (where DMAIC may support in validating outcomes from the optimal problem solution).

The approach presented in this paper proposes the application of supernetwork framework in different steps of the DMAIC cycle, so as to combine the formalism for the modeling and analysis of complex decision-making problems, which is typical of supernetworks, and the quality improvement methodology of Lean Six Sigma.

The first phase of DMAIC cycle is the Define phase. It represents the definition of the problem, where the problem is described in terms of process capabilities and objectives for project-based improvements. Here the supernetwork model is defined and it is depicted through a multilayer graph representing the network topology of patient flow within the Hospital system. In this phase relevant CTQ (critical to quality) indexes requiring optimization are also identified.

During the Measure phase, data valuable for the analysis are collected. The quality characteristics that reflect improvement in patient satisfaction and CTQ identified in previous step are measured, and the metrics of data on which the improvement efforts will be based are provided. This phase collects data that are needed to the computation of function cost to be optimized.

In the Analyze phase, data collected in previous steps are analyzed, for identifying necessary designs and process changes. During such phase, it is possible to find out all the probable causes affecting CTQ variability and consequences it can involve.

Once collected data and identified causes possibly affecting Hospital system performances, possible interventions for processes improvement are identified in the Improve phase. Here supernetworks are used to identify the optimal values for relevant CTQ, which could optimize patient flow, and improve Hospital system quality and patient's satisfaction.

Finally, during the Control step, the process and its CTQ are monitored using quality management tools to prevent system from degrading and ensure that the performance improvements are reached and always maintained.

IV. A Case Study: Emergency Department

Here we demonstrate how the proposed approach can be successfully applied to the modeling and optimization of the patient flow in the context of an Emergency department.

Each phase composing the DMAIC implementation cycle will be described in terms of objectives and performed activities.

A. Phase1: DEFINE

To better understand the problem, the complete patient flow through the various production units of an Emergency Department has been analyzed, from the patient's arrival at the hospital to his discharge, admission or transfer, and criteria which could affect this flow, in terms of time, costs and required efforts have been identified.

In this phase, the internal critical quality parameters that relate to the patient wants and needs have been evaluated. Main attention has been paid to the overall patient "leadtime" (from the arrival to the ED to the leaving), and to parameters that could reduce it.

Fig. 3 shows the network topology associated to the complete patient flow within the ED.

As depicted in the diagram, flow begins with the arrival of the patient at the Emergency Department, by ambulance or walking in.

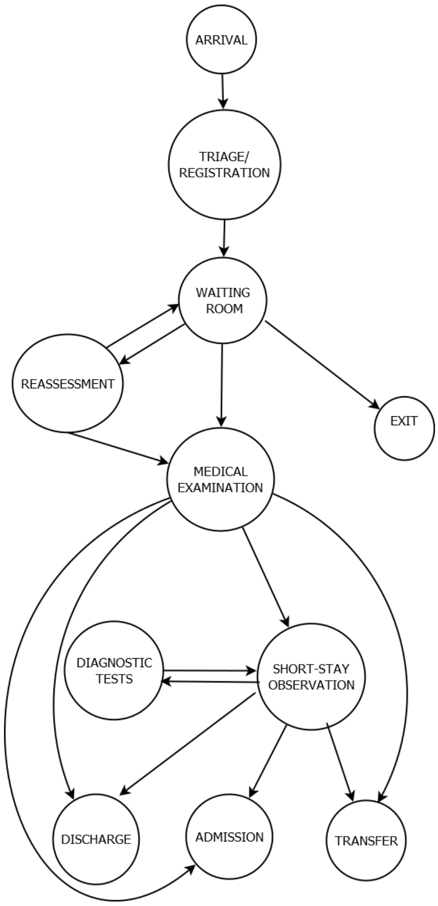

Figure 3. ED patient flow network topology

Once arrived, patient will first come into the waiting room where he will be assessed by a triage staff member, usually a nurse that checks patient's vital signs (such as temperature, heart rate, blood pressure, and breathing) and assigns him a code, depending on the criticity of his health condition.

There are four distinct codes that can be assigned: red code, yellow code, green code and white code. Red code represents the highest level of emergency. It deals with patients whose vital signs are critical and whose lives are in imminent danger. These patients are given absolute priority and are immediately admitted to the medical examination. Yellow code represents a very serious situation, but one where the patient's life is not at risk. It is a priority assigned to patients who need immediate attention, but whose vital signs are not comprised in any dramatic way. These patients are evaluated by the doctors as rapidly as possible. Green code is assigned to patients facing non critical situations, whilst white code deals with patient which is not suffering and whose health disease could be managed by the family doctor and does not require a prompt care.

After having been assigned a triage code, patients wait for their turn at the waiting room. Waiting time depends on the assigned code and on number of people with the same code or higher one coming first. While waiting for the medical examination, patient symptoms are periodically re-assessed by triage nurses (frequency depending on the code severity), so as to monitor patient's health conditions and promptly reassign a different code, in case they get worse.

Once you are in an examination area, an emergency physician examines the patient, monitors his vital signs and decides for discharge, admission to hospital, transfer to other facility or moving to short-stay observation room. During the observation period, physician can possibly order diagnostics tests for the patient (e.g., x-ray, blood, electrocardiogram), which could help to make the right diagnosis and decide next step in the care process (discharge, admission to hospital, transfer to other facility), depending on the severity of the patient’s conditions and resources currently available in the hospital structure.

B. Phase2: MEASURE

In order to measure the problem and identify fields on which the improvement efforts needs to be devoted to, data about ambulatory care visits to hospital emergency departments of Italian region Lazio during summer season have been collected.

Collected data concern different typologies of patients, distinguishing between patients waiting for Triage, patients waiting for medical examination, patients in short-term observation, and patients waiting for admission or transfer to other facility.

These data have been in turn further divided into different sub groups, depending on the priority of patients' treatments, assigned on the basis of the severity of patient condition (red code, yellow code, green code, white code).

Data collected this way have been investigated. First they have been divided into four distinct time slots, depending on the time of arrival and so as to have a uniform distribution within each time slot. Further, their average value has been calculated, so as to identify current “demand” for emergency department care.

C. Phase3: ANALYZE

Once data have been collected, supernetwork framework has been used to define the objective function to be minimized, representing the stay time of patients at the Emergency department and strictly dependent on variables involved in the emergency care process.

Here variables include resources available at the Emergency department (i.e. physicians, nurses responsible for triage execution, number of beds available in the short stay observation rooms, availability of staffs and tools devoted to transfer to other facilities).

Outcomes reveals that the patients’ outstay within the Emergency Department is mainly caused by five variables, as shown in the Ishikawa diagram in Fig. 4, generally used to easily identify main aspects affecting a problem:

Average values for collected data are shown in Table I, Table II and Table III. Tables report a greater number of patients, both waiting for care and already under treatment, in the timeslot from 1pm to 9pm, whilst, in the same timeslot, less are patients waiting for transfer and the ones in short-stay intensive observation. Timeslot generally facing minor patient flow is the one from midnight to 8am.

It is worth to emphasize that there are no patients waiting for triage execution, whilst a lot of patients are waiting for transfer to other facility. It leads to think that resources devoted to triage are adequately dimensioned (triage is executed soon after patient arrival), whilst, on the other hand, issues may affect transfer process, that could require optimization improvements.

TABLE I. PATIENTS WAITING FOR MEDICAL EXAMINATION

Patients Waiting					
Time slots	RedC.	YellowC.	Green C.	White C.	Triage
00:00/08:00	0	0	1	0	0
08:00/13:00	0	1	4	1	0
13:00/21:00	0	1	6	1	0
21:00/00:00	0	1	5	1	0

TABLE II. PATIENTS UNDER CARE

Patients in Treatment				
Time slots	RedC.	YellowC.	Green C.	White C.
00:00/08:00	0	4	4	0
08:00/13:00	1	5	7	0
13:00/21:00	1	6	8	0
21:00/00:00	1	5	6	0

TABLE III. PATIENTS WAITING FOR TRANSFER AND IN SHORT-STAY OBSERVATION

Time slots	Patients waiting for transfer	Patients in short-stay observation
00:00/08:00	6	4
08:00/13:00	6	4
13:00/21:00	5	3
21:00/00:00	5	3

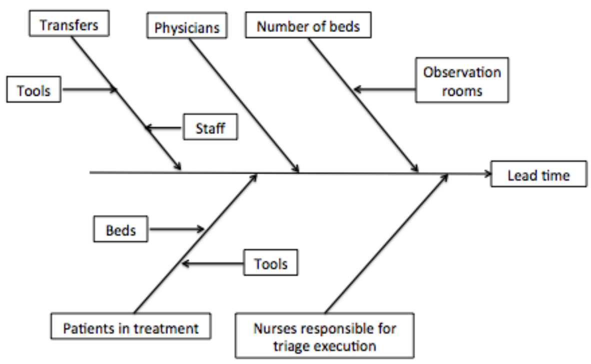

Figure 4. Ishikawa diagram

D. *Phase4: IMPROVE*

The goal of the DMAIC Improve phase is to identify a solution to the problem that this paper aims to address. This also involves brainstorming potential solutions, selecting solutions to test and evaluating the results of the implemented solutions.

Potential solutions have been identified calculating the objective function defined in the Analyze phase and optimizing it.

The solution of the associated optimization problem allows to find out optimal values for variables involved in the process, that are values to be implemented in order to minimize the stay time of patients at the Emergency department, assuming the current "demand" for ED care is the one measured during the Measure Phase.

To solve the optimization problem Matlab has been used; it contains useful toolbox which provides solvers for linear, quadratic, integer, and nonlinear optimization problems.

E. *Phase5: CONTROL*

This is the last phase of the implementation cycle, where overall system (including required changes identified in Improve phase) is monitored so as to ensure that the flows continue to work well, produce desired output results, and maintain quality levels.

Control phase is a fundamental step in the improvement of complex systems, as Hospital Information Systems are.

Patient flow should be continuously monitored to easily identify and solve issues, and guarantee a continuous improvement of the system, which is also the objective of Lean Six Sigma methodology.

V. CONLUSIONS AND FUTURE WORK

In this paper, we proposed a structured approach based on Supernetwork framework and Lean Six Sigma methodology to model and optimize patient flow in the context of a Hospital Information System. Then, to validate such approach, we discussed a case study, where it has been successfully used to model and analyze the patient flow in an Emergency Department, and evaluate possible corrective actions which could reduce patient lead time and improve quality of care. The approach proposed in this paper has proven to be extremely valuable to analyze the problem in a systematic way, incorporate multi-criteria into the decision-making process, provide tools to study the problem, allow applying efficient algorithms for computation, and provide visual aids to see the dynamic changes.

For its characteristics, this approach and its associated tools could be successfully used and applied to the business improvement of the whole Hospital Information System (not only to the Emergency Department), and this is part of our ongoing research.

For the same reason, we think this approach could be effectively employed for the modeling and analysis of complex decision-making problems, characterized by the need of optimizing capacity planning and resource allocation, reducing wastes and improving quality of services to end users.

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Chiara Cirrone was born in Catania, Italy, in 1988. She received the degree in Management Engineering from the University of Catania, in 2012. Her current research interests include the study of methodologies of problem solving within healthcare optimization.

Eleonora Di Pietro was born in Catania, Italy, in 1974. She received the degree in Computer Science Engineering, specialisation in information systems, from the University of Catania, Italy, in 1998.
In 1999 she joined Nokia, where she gained experience in ICT systems, developing competence in different telecommunications areas and in distributed enterprise application architecture and development. Currently she is collaborating with the University of Catania. His current research interests include the study of methodologies of predictive statistical and multivariate analysis devoted to disease management and classification, and the application of supernetworks framework to complex decision/making problems within healthcare management.

Aurelio La Corte received the degree in Electrical Engineering from the University of Catania in 1988, and the PhD in Electronic Engineering and Computer Science in 1994. From 1994 is at the University of Catania. He is an associate professor in Telecommunication Engineering. His scientific interests include digital signal processing, distributed systems and bio-ispired models for information security. He has authored or co-authored about seventy research papers, published in international journals and conference proceedings.

Alfina Anna Torrisi was born in Catania, Italy, in 1989. She received the degree in Mathematics from the University of Catania, Italy, in 2013. Currently she is working at the University of Catania, Italy. Main research interests are the study of optimization methods and theory supernetwork, and the possible applications of supernetwork in real contexts, with special attention to the knowledge supernetwork

