# Literature Review and Classification of Performance Analysis Methods: Hospital Supply Chain

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**Abstract**

Recently, a significant increase of the number of research works has been observed in the health field. In fact, several methods for organizing flows and managing resources and tasks have been proposed to improve the performance of the global hospital supply chain. This improvement regarding various links of the hospital supply chain is considered as a quote for hoisting the healthcare process and organizing work in its agencies.
Moreover, several performance analysis methods were used in order to confront the major problems of this area. Two main approaches are the origin of these methods: the modeling and simulation approach and the optimization based on simulation approach.
The main goal of this work is to present a literature review of the main techniques of modeling and performance analysis used in various research projects in the hospital field. This literature review will be complemented by a study of analysis and classification of the previous techniques. It is about a review in which will be proposed a conceptual model of performance analysis process and the techniques most adapted to the different characteristics and components of the hospital system.

**Keywords**
Hospital supply chain; modeling; simulation; performance analysis; optimization.

## 1. Introduction

The performance improvement of the hospital supply chain continues to be the major reflection of researchers in the healthcare field. In fact, several strategic management policies have been revised in order to clarify the key points of performance improvement of the hospital system. It is about the analysis of performance in order to highlight aspects and action variables that influence directly the hospital system.
According to Beamon (1999), each performance measurement system must use each of the three types of measure (Measure of resources (R), Measure of outputs (O), Measure of flexibility (F) (how the system reacts to uncertainty)) as essential elements for successful operation of measuring the performance of a supply chain.
In the healthcare sector, Sicotte (1998) determined four main functions to define the performance of a hospital: achievement of goals, adaptation, production and maintenance of values. Of their share, Neely et *al*. (1995) have linked performance measurement techniques to the following four dimensions: quality, time, cost and flexibility.
In the same context, Minvielle (1996) linked performance with optimization of quality, costs and lead times. Indeed, several research studies have been carried out in recent years by acting on these three aspects using analysis and performance improvement methods. In (Jacquemin, 2011) and (El Oualidi et *al*., 2010), the authors developed tools for assessing the performance of the patient journey in the studied unit in order to act on the dimension of lead times (decrease of patients waiting time). Su and Shih (2014) developed a model of simulation of the emergency department of a university hospital in Taiwan in order to reach a high level of performance with a minimum of mobilized resources and this within a framework that combines cost-effectiveness, efficiency and quality of care.
In fact, researching in the literature the different methods of analyzing the performance of the supply chain places us in front of various channels, each with its features, dimensions and measuring techniques.
Based on this context, the present work uses as a starting point a set of methods for analyzing the performance of the hospital supply chain extracted from the literature. Indeed, it comes to present in the first place a state of the art of

these different methods. This state of the art will be evaluated later by a classification study and a conceptual model of performance analysis process will be deduced from this work by the end.
The remainder of this paper is presented as follows: In section 2, we present a literature review about the different definitions given to hospital supply chain and its global structure. Then, a benchmark of different performance improvement methods including supply chain modeling and simulation techniques is given in section 3. In section 4, we give our methodology of research, the classification study and the conceptual model of performance analysis process deduced from the literature review analysis.

## 2. The Hospital Supply Chain

### 2.1 Literature Review

Through the literature, several definitions have been affected to the hospital system. A brief review of these definitions lets us say that this is a complex area; considering the large number of flows (physical flow, information flow and financial flow) as well as the different types of resources mobilized to ensure the proper functioning of its institutions and to satisfy the primary customer which is in this case 'the patient'.
The hospital system can be characterized by an open system that interacts with external entities (medical or logistic service delivery entities) (Andre and Fenies, 2007). It is clear that an analogy between hospital system and industrial system ((Artiba et *al*., 2004); (Féniès et *al*., 2004)) is possible if we consider the resemblance between the principle of production, nature of stakeholders and orientation of flows (Andre and Fenies, 2007).
A comparison in this context was carried out by Jokar (2001) between manufacturing logistics and hospital logistics according to five main criteria: the product life cycle, basic activities, support activities, processing activities and specific flows. Thus, in hospital logistics, the use of the concept of performance has passed from the qualification of the results of medical treatments to a qualification of the organizational dimension of the sector and the quality of the care service (Jlassi, 2011). In fact, improving the performance of this sector requires hospitals to approach logistics which deals with the management of material flow and patient flow (Hammami et *al*., 2004).
Throughout the years, many researchers in this field have tried to define the hospital supply chain and each of them has developed a set of dimensions that he considers indispensable to constitute an integral definition of this supply chain (technical and managerial aspects (Hassan, 2006)).
Boyer et *al*. (1982) added the notion of support logistics; this logistics concerns all supply, handling, installation and maintenance activities. For their part, Chow and Heaver (1994) have assigned three main activities to hospital supply chain: supply, production and distribution. According to (ASLOG (Association française de la Supply chain et de la LOGistique), 2002), hospital supply chain consists of managing the physical, patients, service and information flows from the suppliers to the patients.
Landry et *al*., 2000 defined the hospital supply chain as:"a set of design, planning and execution activities that enable the procurement, inventory management and replenishment of the goods and services surrounding the delivery of medical services to patients".
Hassan (2006) proposed the following definition: "*Hospital supply chain is the set of design activities, planning, procurement management, manufacturing (goods and services), delivery and return management, from the provider to the beneficiary (patients), taking into account all the trajectories of the patients in the hospital without which there is no product flows (pharmaceutical). These activities are driven by the information flow between the various partners in the supply chain and lead to financial flows. The aim is to provide optimal service for the quality and safety of patient care*".
Thus, these multiple definitions given by the literature, lead us to conduct more deeply our research in the hospital field in order to understand the detailed structure and the different stakeholders of the corresponding supply chain.

### 2.2 Structure of the Hospital Supply Chain

In the literature, several authors have attempted to detail the structure of the hospital supply chain and to disclose the different flows that are internal to this structure or in relation to external stakeholders.
Swinhart et *al*. (1995) provided health facilities with five main activities. They argue that the implementation of these activities involves several types of inputs (patients and primary entrants) and gives rise to several types of outputs (intermediate outputs and final outputs). Moreover, Sampieri (2002) was based on five factors related to the life cycle of the product (design, production, exploitation, distribution, destruction or recycling) in order to establish its proposal for the structure of the hospital supply chain.

Hassan (2006) has developed a proposal in this direction. The proposed structure focuses on the pharmaceutical component of the institution and has three levels:

- An upstream level whose main players are the manufacturers or suppliers of the pharmacy. The latter are responsible for the supply of pharmaceutical products to the establishment pharmacy.
- A first downstream level concerned by the relationship between pharmacy and other services. The main role of the pharmacy is to supply the pharmaceutical products received from the suppliers with or without transformation to the different services.
- A second downstream level for the management of stocks, the supply of pharmaceutical products to patients and the management of returns.

Based on these definitions which implement the levels and components of the hospital supply chain, we propose the structure detailed in the figure below:

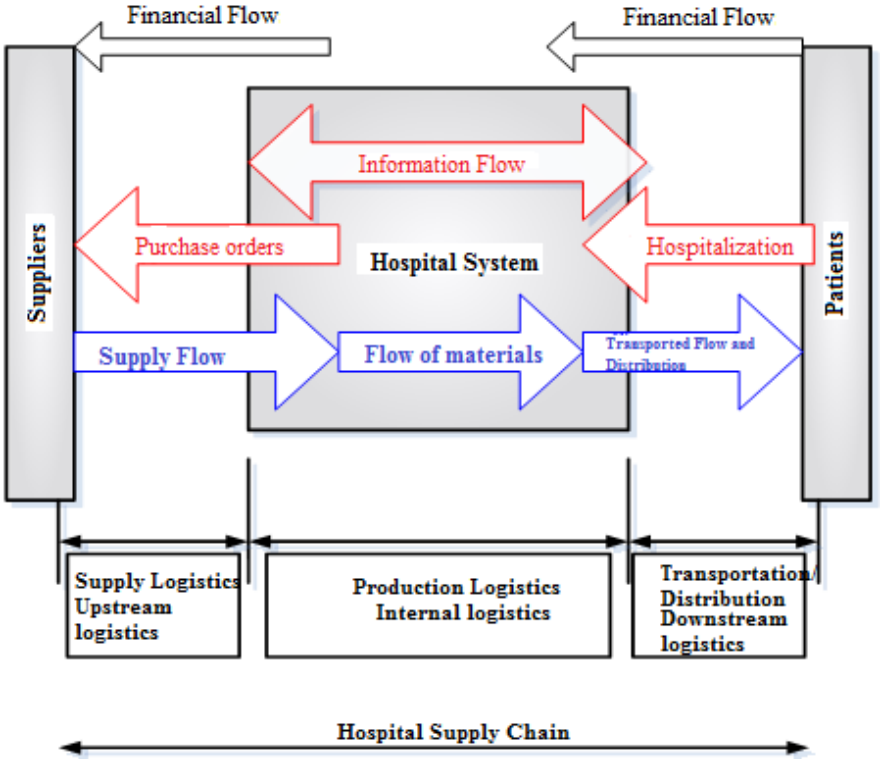


Figure 1. Proposal for the structure of the global hospital supply chain.

## 3. The Performance Improvement Methods in the Hospital Supply Chain: Literature Review

### 3.1 Performance Improvement Methods

The performance analysis can be used either to design a new system (or change an existing system), or to control an existing system (steering by performance) (Matthieu, 2004).

The literature notes two main and different notions in terms of the tools to be used and the strategic horizon to be considered: the notion of performance analysis and the notion of performance measurement. Indeed, the first concept involves estimating the actions needed to manage system performance, while the second term means the measure of the intrinsic value of objects (Burlat et *al*., 2003).

Tahon and Frein (1999) suggest two types of performance analysis procedures:

- **Priori approach:** To establish a model and analyze it to achieve its performance. These will be compared later with the assigned objectives in order to propose changes on the action variables of the model.
- **Posteriori approach:** To measure the different performances of an existing real system. Then, compare these measures with the assigned objectives and highlight the actions to improve the system.

In this work, we will look at the posteriori performance evaluation approach because the major studies in the hospital system focus on identification and improvement of existent real system. The figure below shows the main phases of this approach according to Tahon and Frein (1999).

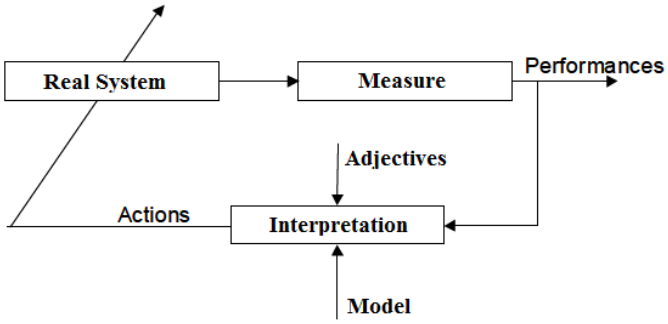


Figure 2. Evaluation of posterior performance (Tahon and Frein, 1999).

By searching through the literature, several research works have tackled the concept of performance analysis in the hospital field (posteriori approach) and various tools have been developed to this purpose. According to Vernadat (1999), the analysis or the improvement of the system performance can be done using the modeling methods to describe the organization of the processes either in order to simulate it later and to compare the different scenarios, or to analyze and restructure them.

In the remainder of this work, we will focus on the set of methods that allow: modeling, simulation, optimization and establishment of the system of performance indicators of hospital supply chain within the framework of the two following performance analysis approaches:

- Modeling and simulation: It is about modeling and simulating the alternatives of action by evaluating the performance of the system in order to achieve the objectives characterized by an interesting number of performance indicators (Elhamdi, 2005).
- Optimization based on simulation: In this approach, it is appropriate to talk about two different modules or process: that of optimization based on the appropriate methods for optimization and that of simulation which allows the evaluation of the supply chain optimization (Ding, 2004).

Based on the concept that the hospital system is a complex system composed of several internal and interconnected sub-components ((Lega and Pietro, 2005); (Litvak et *al*., 2008); (Zonderland et *al*., 2010); (Ouzayd, 2014)), our present work will affect the main production flow within the hospital and thus cover all research studies of patient flows and different administrative flows and resources which are related to primary services such as operating theaters, emergency services, consultation centers,... Two different types of studies have been found in the literature (Villa et *al*., 2014): studies that focus on the planning and optimization of singular units of care production ((Bhattacharjee and Ray, 2014); (Caunhye et *al*., 2012)) and the most recent studies of operations management which propose the models and the theories dealing with the causes of the current problems which are related to the patient circuit in the hospital ((Marshall et *al*., 2015); (Jacquemin, 2011); (Hassan, 2006); (Jlassi, 2011); (Gourgand et *al*., 2007)).

In other words, the researchers tried to analyze the performance of the patient's trajectory by reacting on the organization of the service studied in order to:

- Minimize the cycle time of the patient journey. ((Jlassi, 2011); (El Oualidi et *al*., 2010) ; (Jacquemin, 2011)).
- Plan and manage in real time the components of the patient's trajectory (Jacquemin, 2011).

In the same context and concerning the methods used in each case study, the literature represents a framework rich in these methods and their attributions.

The authors of (Jlassi, 2011) and (El Oualidi et *al*., 2010) have adopted the modeling and simulation approach in order to minimize the cycle time of the patient journey within the emergency department. In fact, the authors of the work (Jlassi, 2011) used the IDEF3x method for the modeling part and the simulation and queue networks for the simulation part, while for the case of the work (El Oualidi et *al*., 2010), the authors adopted the SADT tool for the modeling phase and the Witness software for the simulation.

Industrial platforms are also developed and adapted by hospital field researchers to exploit their strengths in managing and producing outstanding results. For example, the author (Jacquemin, 2011) used industrial planning software (PREACTOR) in order to manage in real time the components of the patient's trajectory in the radiotherapy and hadrontherapy centers by adopting the approach of optimization based on simulation.

In the work (Matthieu, 2004), the author has tried to develop a system of performance indicators based on the determinants of performance and the follows perspectives: Efficiency, Effectiveness and Pertinence (DEEP) in six

main stages. (Fig.3). It is based on the principle of a set of modeling methods (ABC / ABM, SADT / IDEF0, GRAI, SCOR, ...) that produce decision or process models and can generate action / decision variables (performance indicators).

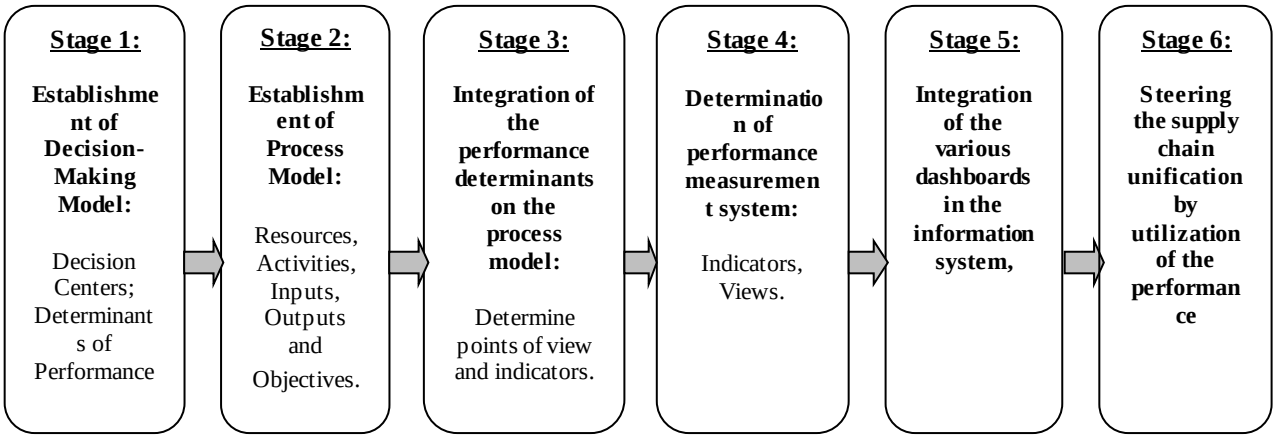


Figure 3. The phases of defining the system performance indicators (Matthieu, 2004)

Concerning the different methods used in the literature for modeling and performance analysis, Bhattacharjee and Ray (2014) have attempted to summarize a set of works dealing with the analysis of hospital systems performance as well as the modeling methods of patient flows that have been used to this purpose. Most recent works that have addressed the modeling of hospital system performance have used a single technique that is simulation (Bhattacharjee and Ray, 2014). The flow of patients into a hospital system can be represented by queue networks and their analysis can be done by analytical queuing formulations, computer simulation, statistical or empirical models or by Markov chain analysis (Bhattacharjee and Ray, 2014).
Similarly, Caunhye (2012) have based on the literature to study all optimization models (Single-objective or Multi-objective, Single-level or Bi-level,…) addressed in the field of emergency supply chain for each activity (models used for pre-disaster operations, post-disaster operations, traffic control and lifeline rehabilitation). Through literature, good reactivity and efficiency are key objectives of optimization works (Caunhye et *al*., 2012). However, most works which are related to emergencies uses reactivity as a primary objective while focusing on: minimizing response times, unmet demand, and distance costs (Caunhye et *al*., 2012).
From the above, we can retain that whatever the approach of analysis of the adopted performance (approach of the modeling and the simulation or approach of the optimization based on the simulation), the methods and the tools to use must to make it possible to achieve effectively the following purposes:

- Step1: To model flows and interactions between several stakeholders,
- Step2: To simulate a set of real data to study the behavior of the model,
- Step3: To analyze the models and results obtained in order to obtain the performance indicators that need to be improved.

### 3.2 Supply Chain Modeling and Simulation Techniques: Benchmark

In this part, we will present some works of the literature dealing with comparative studies between modeling and / or simulation methods. These analytical studies were done in the context of comparing approaches and methods used in the performance analysis process according to their level of adaptation and objectives types.
According to Trilling (2004), modeling approaches are divided into four categories (structured, systemic, process-oriented or object-oriented approaches). Indeed, each category represents the framework and nature of objective to be achieved by using the methods it encompasses. (Figure.4)

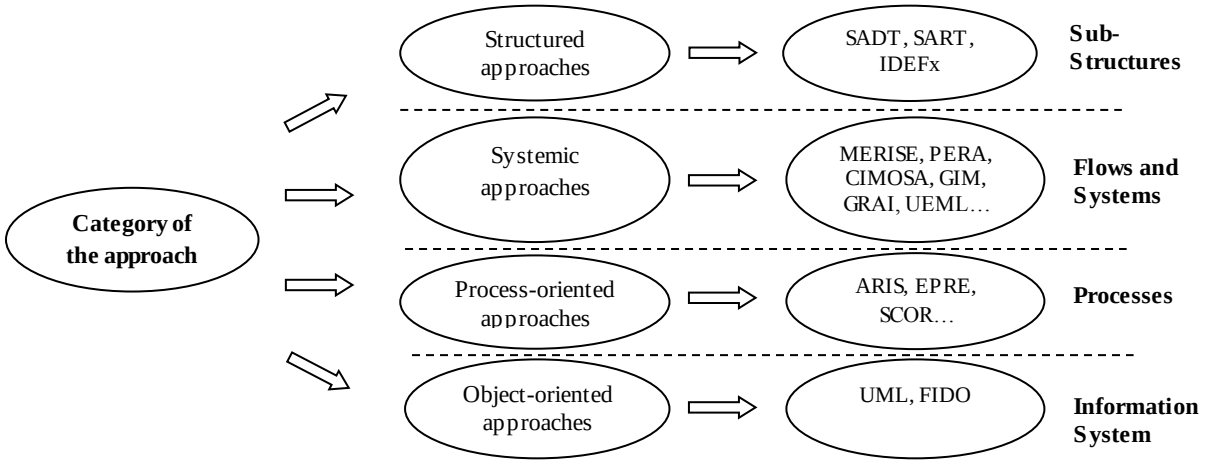


Figure 4. Categories and modeling methods of modeling approaches (Trilling, 2004)

On the other hand, a study on modeling and performance analysis of the patient flows was given by Bhattacharjee and Ray (2014) according to the type of problem to be solved and characteristics of patient flows to be implemented. (Table.1)

Table 1. Patient flow modeling techniques (Bhattacharjee and Ray, 2014)

| Technique of patient flow modeling | Patient flow specificity | Objectives |
|---|---|---|
| Analytical Queueing Theoretic Models | - Minimum number of patient flows steps,<br>- Homogeneous patients;<br>- Markovian inter-arrival and service time distributions.<br>- Constant system. | - Performance measures(waiting time, utilization, congestion, …) |
| Markov Chains and Compartmental | - Operational and clinical flows of patients | - Capacity scheduling<br>- Resource allocation |
| Discrete Event Simulation | - Important number of patient flows steps,<br>- Important number of classes of patients,<br>- Coplex patient priorities and routing probabilities.<br>- System under consideration. | - Capacity scheduling,<br>- Resource allocation |
| Statistical or Empirical Models | - Operational and clinical flows of patients | Extracting for different patient classes informations about patient pathways. |

In a deeper study, Matthieu (2004) has tried, within the framework of development of a system of performance indicators, to analyze a set of modeling methods based on criteria of the reference proposed by the CEN standard (CEN ENV 40003, 2001). Based on this latter, we proposed an alternative classification which will be presented in the following section.

# 4. Conceptual Model of Performance Analysis Process

### 4.1 Research Methodology

To succeed the main work of this article, which is based on analysis and review of the literature of different modeling methods for improving performance in hospital systems, a working methodology based on the following steps is adopted:

**Step 1:** To look for works that address modeling and performance analysis in hospital systems. This is a web-based search in electronic databases; considering their great advantage of updating new researches published in real time. The electronic databases used are as follows:

- ScienceDirect ;
- DPLB ;
- IEEE;
- Springer;
- Google scholar;

In this research, the following key words were used: Hospital supply chain; modeling; simulation; performance analysis; optimization,...

**Step 2:** To sort the desired works in the previous step in order to respect the framework of study; refine the database obtained and eliminate any deviation from the main objective.

**Step 3:** To develop a framework for classifying modeling methods used in the literature; this classification framework uses the following criteria:

- Techniques;
- Criteria of methods analysis: specification, conception, implementation, functional description, organizational description, decision-making description, human resources analysis, technical resources analysis, Information Flow Modeling, Physical Flow Modeling, Type of Formalism, Granularity, Complexity Management;
- Objectives.

**Step 4:** To classify methods of the literature according to the classification framework.

**Step 5:** To design a conceptual model of performance analysis based on methods used in the literature. In fact, this conceptual model will allow modeling the performance analysis process according to 3 main paths which we are deduced from our analysis of the literature.

### 4.2 The Modeling Methods: Application of the Classification Study

Our classification study aims to analyze the adaptability of the modeling methods, used in the process of performance analysis, to the various components of the hospital supply chain. To do this, we tried at first to gather the most used techniques in the literature concerning the hospital sector and to classify them according to a set of criteria (see Table 3). The choice of the latter was made on the basis of objectives related to the performance analysis, namely the type of contribution, possibility of exploitation of the technique, analysis of technical or human resources, granulity and modeling of the different flows (physical, financial and information). Towards the end, a deduction of the overall objective was achieved for each technique.

Table 2. Classification of modeling methods according to selected criteria and global objectives.

| Modeling Methods | | IDEFx | | | GRAI/GIM | | ARIS | UML | Petri Networks | BPMN | SCOR | ABM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IDEF 0/SA DT | IDE F2 | IDE F3 | GR AI | GI M | | | | | | |
| **Works** | | ((Trilling et *al.*, 2004); (Vincent, 2008); E(l Oualidi et *al.*, 2010); (Bertrand et *al.*, 2010)) | | (Jlassi, 2011) | (Trilling et *al.*, 2004) | | ((Trilling et *al.*, 2004); (Hassan, 2006); (Chabrol et *al.*, 2006); (Gourgand et *al.*, 2007)) | ((Ouzayd et *al.*, 2011); Ouzayd et *al.*, 2012); (Vincent, 2008) ; (Staccini et *al.*, 2001)) | ((Sampath et *al.*, 2006) ; (Jlassi, 2011) ; (Vincent, 2008)) | (Mezouar et *al.*, 2016) | ((Mezouar et *al.*, 2016); (Hassan, 2006)) | ((Marshall et *al.*, 2015); (Pombo-Romero et *al.*, 2013)) |
| **Analysis Criteria** | **Specification** | Yes | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes | No | Yes |
| | **Conception** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| | **Implementation** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No | Yes |
| | **Functional Description** | Yes | Yes | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| | **Organizational Description** | No | No | No | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| | **Decision-Making Description** | No | No | No | Yes | No | Yes | No | Yes | Yes | Yes | Yes |
| | **Human Resources Analysis** | No | No | No | No | Yes | No | Yes | Yes | Yes | No | Yes |
| | **Technical Resources Analysis** | Part l | Yes | No | Yes | GIM PLA NT | Yes | Yes | Yes | Yes | No | Yes |
| | **Information Flow Modeling** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| | **Physical Flow Modeling** | Yes | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| | **Type of Formalism** | Graphic | | | Grid | | Graphic | Graph ic | Graphic | Graphi c | Graphi c | Graph ic |
| | **Granularity** | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| | **Complexity Management** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Objectives** | | Hierarchical description of hospital systems | Design of models for simulation | Description of flows and business processes | Analysis and design of decision systems | Analysis of integrated production systems | Simulation, analysis and improvement t of the supply chains modularity | Architectural, Organizational, and dynamic description of systems | Description of systems behaviors. Planning and scheduling of resources. | Description of business processes | Supply chains models of systems | Simulation of agents interactions of system |

### 4.3 Conceptual Model for Performance Analysis Process

Our work of review and analysis of the literature has allowed us, in addition to the study of classification of modeling methods, to propose a conceptual model to identify the major steps of performance analysis process using a Petri Nets language. For each case study, it is first necessary to determine the environment, namely the system status and the type of objective, to subsequently determine the methodology of performance analysis (Path N °1, Path N °2 or Path N ° 3). After the simulation phase, a generation of performance indicators will be unavailable for the analysis of GAP and the choice of improvement actions to be applied. These different steps are detailed in the figure below (Figure 5):

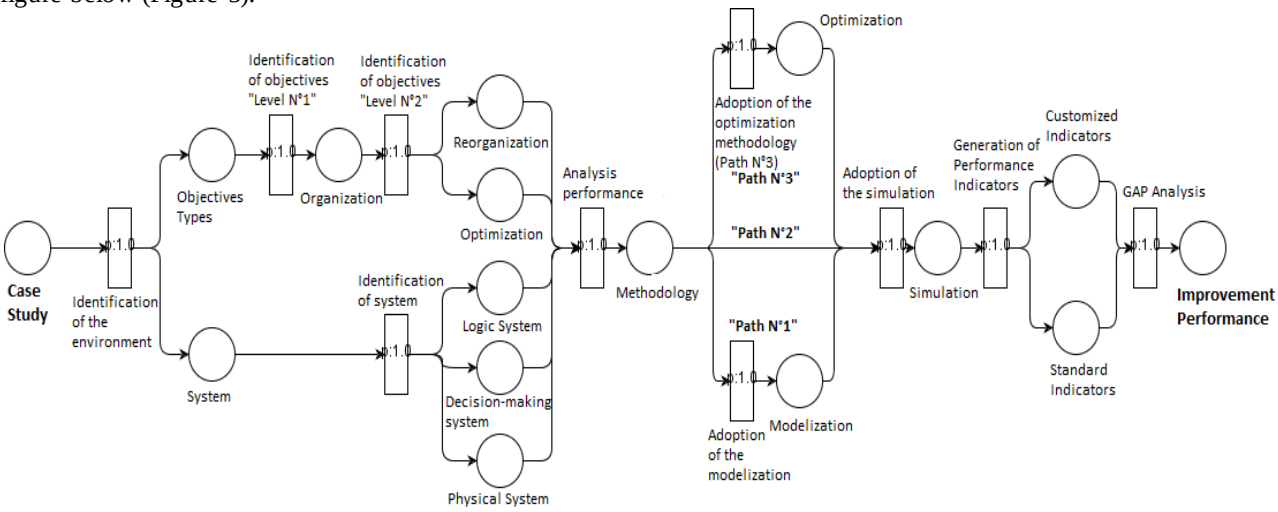


Figure 5. Conceptual model for performance analysis process.

## 5. Conclusion

In this work, we have firstly introduced the performance, its measures and dimensions given by the literature. In the next step, we have presented a literature review about the different definitions of hospital supply chain and its global structure. Then, we have given a benchmark of performance improvement methods corresponding to hospital supply chain, especially the patient's trajectory. In this benchmark, we have focused on modeling and simulation techniques. Afterwards, we have given our methodology of research which is adopted in this work. This later is based on the previous modeling methods extracted from the literature. In fact, a classification study has been realized on the basis of a set of selected criteria and a conceptual model has been deduced by the end to detail the major steps of performance analysis process. In our future work, we plan to develop a new method that combines the most appropriate techniques according to the previous classification study to analyze the performance of the cold supply chain of hospital system.

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